2005 Juvenile Chinook Duwamish River Studies

<u>Study 1:</u>

Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary

<u>Study 2:</u>

Fish Assemblages and Patterns of Chinook Salmon Abundance, Diet, and Growth at Restored Sites in the Duwamish River

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Study 1:

Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary

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Study 2:

Fish Assemblages and Patterns of Chinook Salmon Abundance, Diet, and Growth at Restored Sites in the Duwamish River

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STUDY SUMMARY AND RESTORATION CONCLUSIONS

This report provides the findings of two salmon studies conducted in the Duwamish River and estuary during 2005. The overall goal of the studies was to provide information that would be useful to planners who are making decisions on how and where to improve salmon habitat in the lower watershed. Study 1 provides information on occurrence patterns of juvenile Chinook salmon in habitats of the lower Duwamish River and estuary in order to identify reaches and habitat types where restoration projects might be most effective. Study 2 compares salmon utilization of habitats that have undergone rehabilitation with adjacent reference sites. Summaries of Study 1 and Study 2 are followed by restoration conclusions developed from both investigations.

Study 1: Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary

An important goal of salmon recovery in the Puget Sound region is to identify and implement habitat rehabilitation projects that will effectively enhance the viability of Puget Sound Chinook salmon. However, prior to implementing these projects, information is needed to determine specific habitat areas and habitat types that may be most beneficial for recovering Chinook salmon populations. Recent research in the Duwamish River and estuary suggests that juvenile Chinook salmon (and other salmonids) are especially abundant in the "Transition Zone", an area where fresh and marine waters initially mix and where large eddies tend to form. Research also indicates that releases of hatchery salmon into the Green River may reduce growth of natural juvenile Chinook salmon and displace them from rearing areas.

Objectives of this investigation were to examine the following questions that are considered high priority in the WRIA 9 Research Framework:

1) *What are the distribution patterns of juvenile salmon between RM 1 and 9 throughout the outmigration period, and how do these patterns correspond to physical habitat conditions (e.g., salinity, temperature, slope, substrate, bank type)?*

2) *What are the growth and feeding rates of juvenile Chinook salmon, and is habitat capacity sufficient to support high growth during periods of high salmon abundance?*

These questions led to the following hypotheses, which were tested in 2005:

- *Natural subyearling Chinook salmon (fry and fingerlings) are more abundant in the Transition Zone compared with other areas in the estuary and lower river;*
- *Natural subyearling Chinook salmon are most abundant in specific habitat types regardless of whether or not they occur in the Transition Zone;*
- *Natural subyearling Chinook salmon are more abundant in off-channel habitats compared with adjacent main channel habitats;*

- *Natural subyearling Chinook salmon are most abundant in nearshore habitats of the Duwamish estuary compared with adjacent mid-channel areas;*
- *Growth and prey consumption of subyearling Chinook salmon decline significantly during periods of high densities of Chinook salmon and other fishes, such as during the release of numerous hatchery salmon.*

Methods

Fourteen nearshore sites were sampled on a weekly basis in the lower Duwamish River (RM 6.6-8.5), Transition Zone (RM 4.6-6.5), and Duwamish estuary (RM 1 to RM 3.5) from February 3 to July 12, 2005. Each site was sampled up to three times per week by a river seine to collect fish present at the site. Purse seine and beach seine data collected during December 2004 to February 2005 for the U.S. Army Corps of Engineers were also used.

Summary of Findings

- Catch rates of natural Chinook in 2005 were low compared with catches in 2002 and 2005. In 2005, Chinook catch rates were low from late January to mid-March, declined in mid-April, then increased slightly late April to late May.

- Hatchery Chinook were present in the Duwamish River beginning in late March and were exceptionally abundant from late May to early June. Chum salmon were the most abundant salmonid captured during the study, with low numbers of pink and sockeye salmon captured as well.

- Densities of subyearling natural Chinook salmon were significantly greater in the Transition Zone area compared with lower river and lower estuary habitats. High catches in the Transition Zone extended from the Turning Basin (RM 5.5) to approximately RM 4.6. The importance of each zone for combined natural and hatchery Chinook salmon varied with time: the Transition Zone had the highest catches of fry and fingerlings late January to mid-May, whereas the lower river produced the greatest catches of fingerling Chinook late May to early July. The lower estuary produced the smallest catches except from February to mid-Match (moderate catches).

- Chinook salmon appeared to select habitats with lower gradient, lower velocities and in response to salinity levels. Chinook salmon were statistically more abundant in low gradient intertidal areas (<4° slope) compared with higher gradient areas (9-16° slope). Natural Chinook tended to be in low velocity areas early in the outmigration season, but did not appear to respond to such areas after late March. Other habitat factors such as presence of bank armoring, natural bank features or restored shorelines were not found to be related to numbers of Chinook. Salinity influenced the distribution of natural Chinook salmon within the study area, but this effect varied with season. During the early migration period, natural Chinook salmon tended to be more abundant in eddy-forming habitats that had relatively low water velocities. Water velocity and eddy formation tended to have less effect on Chinook salmon after late March.

- During the early migration period (February 3 to March 22), Chinook salmon were more abundant in brackish water areas (>2 ppt) compared with freshwater habitats (<2 ppt). From late March to early July, Chinook salmon were more abundant in freshwater habitats (<2 ppt) compared with more saline areas (>5 ppt); abundance was intermediate in habitats having intermediate salinity. These findings are consistent with those from the Transition Zone and lower river zone comparisons, and provide evidence that early migrating Chinook fry (February to March) rapidly move through the lower river (low salinity) and hold in the Transition Zone and other brackish waters, whereas later migrating fingerlings hold and rear in the lower river habitats, then move through brackish water areas relatively rapidly. The findings indicate that the importance of habitat zones (lower river, Transition Zone, and lower estuary) varies with life stage of Chinook salmon.

- Densities of subyearling salmon were significantly greater in off-channel habitats compared with mainstem habitats located in the lower river, but significantly less in off-channel habitats in lower estuary. This pattern may reflect behavioral differences of Chinook inhabiting freshwater vs. marine habitats. However, the results are based on only two site comparisons, one in the lower river and one in the lower estuary.

- Natural subyearling Chinook salmon were considerably more abundant in nearshore compared with mid-channel habitats of the Duwamish estuary during late January and February, i.e., the entire period when Chinook were sampled in the mid-channel.

- Mean length of natural subyearling Chinook salmon captured in the lower river and estuary increased steadily from 37 mm on January 20 to 82.8 mm on May 10, and then declined slightly to 78 mm. Chinook size and growth rate were greater in 2005 compared with previous years apparently because water temperature was high, water flows were low, and juvenile Chinook abundance was low.

- Total prey weight in relation to body weight was moderate during late January to late March (avg. 1.4%), relatively low from late April through mid-June (avg. 0.6%), and high in late June (avg. 1.9%) when few Chinook salmon remained in the watershed and water temperature was relatively high.

- Consumption of prey by Chinook salmon was consistently low during three weeks when hatchery salmon were highly abundant in the lower river and estuary, but low feeding also occurred prior to the arrival of hatchery Chinook salmon. This pattern confounded the analysis to evaluate whether hatchery salmon influenced feeding rates of natural Chinook salmon.

- Adult, pupal, and larval midges were the most frequent prey observed in both natural and hatchery Chinook salmon throughout the study period.

- Available data allowed for rough estimation of residence time in the middle and lower Green River. Residence time between RM 34.5 and RM 1-8.5 was approximately 8 days during early February, increasing to 13 days in mid-February, and to 25 days during late February to mid-April (range: 19 – 32 days). Residence time after mid-April was not estimated in 2005 because model assumptions were violated, but an otolith study indicated residence times declined after late May.

Study 2: Fish Assemblages and Patterns of Chinook Salmon Abundance, Diet, and Growth at Restored Sites in the Duwamish River

The Duwamish Waterway, once the estuary of the Duwamish River located in Seattle, Washington, is now an industrial waterway, with almost no remaining natural habitat. However, it is still an important rearing area for threatened juvenile Chinook salmon and other fish, and is also the site of a number of habitat restoration projects of various sizes and configurations. Based on previous research, these restored sites appear to be productive for juvenile salmon, but the majority of this research has been based on indirect measures of productivity, such as amounts of potential juvenile salmon prey present at the sites. These types of measures can estimate the potential for juvenile salmon benefit from a habitat, but cannot determine the probability that salmon will use the site or derive real benefits such as increased growth or survival from it. This study tested the function of restored wetland sites vs. reference non-restored sites in the lower Duwamish River for juvenile Chinook salmon by quantifying fish presence at the sites, analyzing diets of juvenile Chinook salmon using the sites, and applying bioenergetics models for juvenile Chinook salmon using appropriate input parameters.

<u>Methods</u>

Studies were conducted at three restored sites in the Duwamish Waterway: Herring's House, in the lower, more saline part of the waterway, and Hamm Creek and Turning Basin, in the upper, oligohaline part of the waterway. The sites had different configurations and sizes, but all consisted of regraded upper intertidal habitats with planted fringing emergent vegetation. Reference sites were chosen adjacent to each restored site representing typical Duwamish Waterway shorelines retained by riprap, with a narrow strip of intertidal mud or sand. Fish were sampled at the sites 10 times from 15 February 2005 to 8 July 2005. Measurements and samples included:

- Recording water temperatures using automated data loggers placed at each site.
- Collecting fish from each site using 60 m length enclosure nets placed at high tide, and fished just before dewatering of each site.
- Determining hatchery vs. "wild" status of juvenile salmon based on hatchery marking.
- Obtaining diets of juvenile Chinook salmon collected by non-lethal gastric lavage.
- Conducting 24-hour sampling to determine consumption rates of juvenile Chinook salmon (for use in bioenergetics modeling).

Both parametric statistics and multivariate techniques were used to detect differences among sites and times. Using the results from field sampling and from other studies, a modified Wisconsin bioenergetics model was developed and applied to test the hypothesis:

- *Restored sites provide increased productivity for juvenile Chinook salmon, as measured by modeled growth rates.*

Summary of Findings

- Twenty three fish species were captured in the enclosure nets, with five species—shiner perch, chum salmon, threespine stickleback, staghorn sculpin and starry flounder making up the majority of the overall catch. The more marine-influenced site (Herring's House) was largely dominated by shiner perch, and had some marine fish not found at other sites, while the two lower salinity sites had more starry flounder, sticklebacks, and sculpins. However, multivariate analysis indicated that site was a less important factor than time in structuring fish assemblages, as the peak species compositions of juvenile salmonids and other fishes changed through time. In several cases, non-salmonid species were very abundant when juvenile salmon were present at the sites, and may compete with the salmon for resources.

- Although there were no statistically significant differences in overall fish densities among the sites, at two locations, Turning Basin and Hamm Creek, taxa richness was higher at the restored sites, and analysis of similarity showed that at Turning Basin and Herring's House restored and reference sites had slightly different fish assemblages.

- The only statistically significant difference found for juvenile salmon among paired restored and reference sites were at the Turning Basin, where juvenile Chinook were significantly more abundant at the restored site. This may be because this site has a relatively unobstructed opening to the main channel of the Duwamish estuary making access easier, or because the salmon densities and residence are greater in the Turning Basin area than in other parts of the estuary and restored site use is density dependent.

- Juvenile Chinook salmon in this study fed on a variety of benthic invertebrates, terrestrial insects, and emergent marsh insects, similar to results from previous studies. Juvenile Chinook had markedly and consistently higher instantaneous ration of food at both the restored and reference Turning Basin sites compared with the other two study sites. This higher ration also translated into higher modeled growth rates at the Turning Basin as compared to the other locations, when the model consumption rate was adjusted for instantaneous ration. These findings could be the result of either more intensive fish foraging there or better prey availability in the area, and they suggest that the benefits to juvenile Chinook salmon of locating future intertidal habitat restoration projects near the Turning Basin may be high.

- The bioenergetics models did not verify the hypothesis that restored sites provided juvenile Chinook salmon with enhanced growth potential: modeled growth rates were similar among the restored and reference sites or were inconsistent among sites and months. This may indicate that prey was not limiting for juvenile Chinook salmon in the lower Duwamish River during 2005, and that salmon acquired adequate food throughout the waterway. Other factors may include lack of precision in the models due to inability to adequately measure in situ consumption rates, or the relatively short time fish were held on the site by the enclosure nets.

2005 Duwamish Research Restoration Conclusions

- Results in 2005 were consistent with previous studies that indicated densities of subyearling Chinook salmon were higher in the Transition Zone (RM 6.5 to at least RM 4.6) compared with adjacent reaches such as the lower estuary. However, lower river habitats also supported large catches of fingerling Chinook salmon during late March through early July. This shift in habitat utilization may reflect different behavioral and physiological responses to salinity by Chinook fry versus Chinook fingerlings.

- Data collected in 2005 and in previous years suggest that priority should be given to restoration projects in the Transition Zone and lower Duwamish River, if possible. While restoration projects in the lower estuary will provide benefits for juvenile salmon, available data suggest that juvenile salmon migrate through this reach relatively quickly and spend relatively little time in off-channel habitats.

- Comparison of rehabilitated versus adjacent reference habitats suggested Chinook salmon may be more abundant in rehabilitated sites having open access compared with either reference sites or with rehabilitated sites having a narrow opening to rehabilitated habitat. This finding suggests rehabilitation projects should consider ease of access of salmon to habitat.

- Instantaneous consumption of prey by Chinook salmon was greater in the Turning Basin compared with the Hamm Cr (lower Transition Zone) or Herrings's House (lower estuary), indicating greater prey availability and/or greater feeding activity at the Turning Basin. This finding suggests relatively high value of locating future restoration projects near the Turning Basin.

- Densities of subyearling salmon were significantly greater in off-channel habitats compared with mainstem habitats located in the lower river, but significantly less in off-channel habitats in lower estuary. This pattern may reflect behavioral differences of Chinook inhabiting freshwater vs. marine habitats. This finding suggests that restoration projects in the lower river should focus on construction of off-channel habitats, whereas projects in the lower estuary might focus on projects along the mainstem.

- Habitats having gentle intertidal gradients and lower velocities tended to support higher Chinook densities. Bank armor and restoration of upper tidal and upland areas were not associated with higher catches. These findings suggest that restoration of salmon habitat should maximize additional intertidal habitat while providing fringe marsh and upland habitat to support prey production.

- Surface area of restored habitats should be maximized in order to support the large numbers of natural and hatchery salmon. Ideal habitats appear to be large areas having gentle intertidal mudflat slopes that are protected from currents while also providing refuge in a channel during low tides.

- Natural subyearling Chinook salmon were considerably more abundant in nearshore compared with mid-channel habitats of the Duwamish estuary during late January and February. This finding provides evidence that restoration projects should focus in nearshore areas.

Restoration in the Duwamish River can be informed by these studies, however, additional considerations should be included in restoration planning. Connectivity and size of habitats are important elements that are likely to increase the cumulative effectiveness of all restoration efforts. Currently, the Duwamish River lacks higher quality habitat between Kellogg Island and about RM 4.6 (C-Flats site). Approximately 3.6 miles of relatively low quality habitat could affect successful rearing and migration of juvenile Chinook and inserting habitat refuge sites along this stretch could be helpful. At each end of this low quality habitat corridor, habitat restoration sites are clustered near Kellogg Island and near the Turning Basin. Clustering habitat sites or expanding out from existing sites are ways to achieve larger habitat areas and should also be considered in future restoration efforts.

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Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary

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WRIA 9 Technical Committee
WRIA 9 Steering Committee

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EXECUTIVE SUMMARY

An important goal of salmon recovery in the Puget Sound region is to identify and implement habitat rehabilitation projects that will effectively enhance the viability of Puget Sound Chinook salmon. However, prior to implementing these projects, information is needed to determine specific habitat areas and habitat types that may be most beneficial for recovering Chinook salmon populations. Recent research in the Duwamish River and estuary suggests that juvenile Chinook salmon (and other salmonids) are especially abundant in the "Transition Zone", an area where fresh and marine waters initially mix and where large eddies tend to form. Research also indicates that releases of hatchery salmon into the Green River may reduce growth of natural juvenile Chinook salmon and displace them from rearing areas.

Objectives of this investigation were to test the following hypotheses that are considered high priority in the WRIA 9 Research Framework:

- Natural subyearling Chinook salmon (fry and fingerlings) are most abundant in habitats within the Transition Zone versus other areas in the lower river and estuary;

- Natural subyearling Chinook salmon are most abundant in specific habitat types regardless of whether or not they occur in the Transition Zone;

- Natural subyearling Chinook salmon are more abundant in off-channel habitats compared with adjacent main channel habitats;

- Natural subyearling Chinook salmon are most abundant in nearshore habitats of the Duwamish estuary compared with adjacent mid-channel areas;

- Growth and prey consumption of subyearling Chinook salmon decline significantly during periods of high densities of Chinook salmon and other fishes, such as during the release of numerous hatchery salmon.

Fourteen nearshore sites were sampled on a weekly basis in the lower Duwamish River (RM 6.6-8.5), Transition Zone (RM 4.6-6.5), and Duwamish estuary (RM 1 to RM 3.5) from February 3 to July 12, 2005. Each site was sampled up to three times per week by a river seine (20 m long x 2 m deep), which was designed to sample lotic waters. We also analyzed data collected during December 2004 to February 2005 for the US Army Corps of Engineers. These data were collected with a purse seine (230 m x 18 m) in mid-channel areas and a Puget Sound protocol (PSP) beach seine (37 m x 2 m) in intertidal areas. We used the data to test the mid-channel distribution hypothesis and to define the initial arrival time of juvenile Chinook salmon in the Duwamish estuary. The findings of the 2005 study are based on 1,114 beach seine sets.

<u>Seasonality of Chinook Salmon in Littoral Zone</u>

The first subyearling natural Chinook salmon was captured at night on December 23, 2004, but Chinook fry were not regularly captured in the lower river and estuary until January 20 (3.1 fry per set), immediately after exceptionally high flows. Chinook catch rates were low from late

January to mid-March (up to 6 fry per set), declined in mid-April, then increased slightly late April to late May (two fry per set). River flows were exceptionally low throughout the study period except in late January. Catches of natural subyearling Chinook salmon in 2005 were 75% and 15% lower than catches in 2003 and 2002, respectively, even though parent spawning escapement was relatively high.

Small numbers of subyearling hatchery Chinook salmon were present in the lower river and estuary beginning in late March, suggesting that some fry planted by the Muckleshoot Indian Tribe (MIT) may have escaped through Howard Hanson Dam prior to the reservoir refill period in spring. Hatchery Chinook were exceptionally abundant from late May to early June (18 to 28 fish per set), corresponding with the release of 3.4 million subyearling Chinook salmon from the WDFW hatchery. Abundance of hatchery Chinook declined sharply from mid-June to early July. The percentage of hatchery salmon among total subyearling Chinook was large, averaging 29% during eight weeks prior the WDFW release of hatchery Chinook in mid-May, and 89% after the release.

Chum salmon were the most abundant salmonid captured in the lower river and estuary during 2005. Approximately 2.4 million unmarked hatchery chum salmon were released into the middle Green River during late March and April. Unexpectedly, a few pink salmon fry were captured, indicating an even year run is beginning to develop in addition to the large increase in odd-year pink salmon. A few sockeye fry were captured indicating that the small river-rearing population continues to persist.

Transition Zone Hypothesis

Statistical analyses indicated that densities of subyearling natural Chinook salmon were significantly greater in the Transition Zone area compared with lower river and lower estuary habitats. High catches in the Transition Zone extended downstream from the Turning Basin (RM 5.5) to approximately RM 4.6. No sampling sites were available between RM 3.5 and RM 4.6. The importance of each zone for combined natural and hatchery Chinook salmon varied with time: the Transition Zone had the highest catches of fry and fingerlings late January to mid-May, whereas the lower river supported the greatest catches of fingerling Chinook late May to early July. The lower estuary supported the smallest catches except from February to mid-Match.

On average, catches of natural Chinook salmon in the Transition Zone versus the lower estuary (RM 1 to 3.5) were 57% greater February 3 to March 21, 259% greater March 28 to May 16, and 118% greater May 23 to July 12. Thus, both Chinook fry and fingerlings were more abundant in the Transition Zone compared with the lower estuary.

Catches of natural Chinook salmon in the Transition Zone versus the lower river (RM 6.6 to 8.5) were 262% greater February 3 to March 21, 16% greater March 28 to May 16, but 39% less during May 23 to July 12, i.e., the period when larger fingerling Chinook were migrating through the study area. Relative abundances of Chinook salmon in the lower river increased over time, whereas abundances in the Transition Zone and lower estuary declined. May 23 to July 12, abundance of natural Chinook salmon in the lower river was 260% greater than in the lower estuary.

Hatchery Chinook salmon were most abundant in the lower river (RM 6.6-8.5) followed by the Transition Zone, then the lower estuary (RM 1-3.5). This pattern was consistent with high catches of natural Chinook salmon in the lower river mid-May to early July.

<u>Habitat Hypothesis</u>

The habitat hypothesis states that Chinook salmon will be most abundant in favorable habitats, i.e., salmon distribution may be patchy rather than continuous within zones. We conducted Analysis of Variance (ANOVA) tests and developed statistical models to describe abundances of natural Chinook salmon in relation to habitat features such as bank armoring, eddy potential, site rehabilitation, river zone (river, Transition Zone, estuary), tide stage, bank slope, water velocity, river discharge, water temperature, surface salinity, statistical week, number of hatchery Chinook salmon, number of chum salmon, and number of shiner perch.

ANOVAs indicated no differences in abundances of natural Chinook salmon occupying habitats having armored vs. un-armored banks, rehabilitated/natural habitat features vs. highly altered habitat, and intertidal substrate type. During the early migration period, natural Chinook salmon tended to be more abundant in eddy-forming habitats that had relatively low water velocities. Velocity and eddy formation tended to have less effect on Chinook salmon after late March.

Chinook salmon were statistically more abundant in low gradient intertidal areas (<4° slope) compared with higher gradient areas (9-16° slope) throughout the study period. This finding might result from 1) lower water velocity, 2) larger surface area of shallow mudflat habitat, 3) availability of prey resources, and/or 4)greater efficiency of the beach seine in low gradient.

Salinity influenced natural Chinook salmon within the study area, but this effect varied with season. During the early migration period (February 3 to March 22), Chinook salmon were more abundant in brackish water areas (>2 ppt) compared with freshwater habitats (<2 ppt). From late March to early July, Chinook salmon were more abundant in freshwater habitats (<2 ppt) compared with more saline areas (>5 ppt); abundance was intermediate in habitats having intermediate salinity. These findings are consistent with those from the Transition Zone and lower river zone comparisons, and provide evidence that early migrating Chinook fry (February to March) rapidly move through the lower river (low salinity) and hold in the Transition Zone and other brackish waters, whereas later migrating fingerlings hold and rear in the lower river habitats, then move through brackish water areas relatively rapidly. The findings indicate that the importance of habitat zones (lower river, Transition Zone, and lower estuary) varies with life stage of Chinook salmon.

Multiple regression was used to further evaluate whether certain habitat characteristics tended to be correlated with catches of natural subyearling Chinook salmon. Data from each site during each week were used in the analysis. Number of natural Chinook salmon per beach seine set could be predicted from the following statistical model:

$$\text{Log}_e \text{ Chinook} = .913 + .030 \text{ (Salinity) (Period)} - .0.029 \text{ (Slope)} - .216 \text{ (Lower Estuary)} - .101 (\text{Log}_e \text{ Perch}),$$

Although each variable was statistically significant, only 8% of the catch variability in 854 seine sets was accounted for by them. No other habitat variables were statistically significant. The model was consistent with the ANOVA analysis, and suggests that natural Chinook catch rates were higher when 1) salinity was high during the early migration period, 2) salinity was low during the later migration period, 3) intertidal slope was low, 4) sampling occurred upstream of the lower estuary, and 5) few shiner perch were present. The model suggests shiner perch might compete with Chinook salmon for resources and that catches tend to be relatively low in the lower estuary.

In the Transition Zone, the smallest Chinook salmon catches occurred at a site consisting of a steep mud slope, natural bank with no armoring, and relatively high velocity during ebbing tides. The greatest catches occurred at a site having a broad, shallow mudflat that remained submerged until approximately 0.0 ft MLLW and was protected from high water velocity.

Off-channel vs. Main Channel Salmon Hypothesis

Statistical tests indicated that densities of subyearling salmon (natural and hatchery Chinook and chum fry combined) were significantly and consistently greater inside an off-channel restoration site in the lower river (Codiga Cove, RM 8.5) compared with the adjacent mainstem area. Catches of salmon were 35% greater in the protected off-channel site compared with the main channel area.

In contrast, densities of subyearling salmon were significantly and consistently greater along the mainstem area of a lower estuary site (Kellogg Island) compared with the side channel area. Catches of salmon were 57% greater in the mainstem area compared with the side channel area west of Kellogg Island.

These findings suggest behavior of subyearling salmon varies from the lower river (freshwater) to the lower estuary (brackish marine water). In the lower river, juvenile Chinook salmon appear to occupy low velocity areas, whereas in the lower estuary they were more abundant along the mainstem.

Onshore vs. Offshore Fish Distribution Hypothesis

Mid-January to late February, 31.2 ± 5.9 Chinook fry per set were captured in 90 PSP beach seine sets (counts expanded for purse seine sampling area), whereas none were captured in 41 purse seine sets in mid-channel. All subyearling Chinook salmon were naturally produced and small (avg. 42 mm). Catch rates of yearling and older salmon in nearshore beach seines were not statistically different from catches in mid-channel purse seines.

Salmon Length and Growth

Mean length of natural subyearling Chinook salmon captured in the lower river and estuary increased steadily from 37 mm on January 20 to 82.8 mm on May 10. On May 16 mean length declined to 78 mm, then length remained relatively constant until a slight increase during late June. The slight decline in mean length on May 16 corresponded with an increase in juvenile Chinook salmon emigrating from the middle Green River (trap data from RM 34.5).

Weekly change in mean Chinook length was used to approximate daily growth rate prior to mid-May. Most of the change in size likely occurred upstream of the sampling areas because many fish continually move downstream. January 20 to March 15, change in daily length was relatively constant and averaged 0.27 mm (0.63% of body length). March 22 to May 10, change in daily length increased to 0.59 mm (0.93%), on average, and was relatively constant during this period.

Mean length and weight of Chinook salmon in 2005 were consistently greater in the lower river and estuary compared with those during 2001-2003. Relatively warm air temperature, low river flows, and low abundances of juvenile Chinook salmon likely contributed to the rapid growth of natural Chinook salmon in 2005. Comparisons of growth at the RM 34.5 trap versus downstream areas indicated that much of the additional growth in 2005 compared with previous years occurred between RM 34.5 and the lower river and estuary.

Prey Consumption

Diets of subyearling natural and hatchery Chinook salmon were examined from fish collected in the Transition Zone area from late January to early July. Total prey weight in relation to body weight was moderate during late January to late March (avg. 1.4%), relatively low from late April through mid-June (avg. 0.6%), and high in late June (avg. 1.9%) when few Chinook salmon remained in the watershed and water temperature was relatively high. Importantly, these prey weight values are not indices of daily consumption rates because prey pass through the stomach at a much higher rate when water temperature is high.

Weight of hatchery Chinook salmon prey was correlated with that of natural Chinook salmon from late April to late June ($R^2 = 0.47$). Prey weight consumed by hatchery salmon was approximately 25% greater than that of natural Chinook salmon, but the difference was insignificant when standardized by body weight. No empty stomachs were observed in Chinook from February to April, but 6% of natural and 4% of hatchery Chinook were empty in May and June. Adult, pupa, and larval midges were the most frequent prey observed in both natural and hatchery Chinook salmon throughout the study period. The data indicate hatchery Chinook salmon readily consumed natural prey in the Transition Zone.

We tested the hypothesis that consumption of prey by natural subyearling Chinook salmon is lower when large numbers of Chinook salmon are present. Median prey weight (% of body weight) declined significantly when greater numbers of total subyearling Chinook salmon were present in the Transition Zone and lower river and estuary sites, but the variability explained by fish abundance was relatively low (25-28%). The significant relationship was largely driven by low prey weight May 24 to June 7 when hatchery Chinook salmon were exceptionally abundant. Prey weight did not decline in response to numerous hatchery chum salmon.

Salmon Interaction Hypothesis

Recent studies in the Duwamish suggested that large releases of hatchery Chinook salmon may reduce growth of natural Chinook salmon or displace them from rearing areas. Growth of Chinook was based on weekly changes in fish length, a method that is commonly used but requires the assumption that fish of different size categories move randomly through the watershed.

From May 9 to May 16, mean length of natural Chinook salmon declined from 82.8 mm to 78 mm then remained relatively constant until a slight increase in late June. This decline corresponded with an increase in juvenile Chinook salmon emigrating from RM 34.5. The decline in length also occurred before a large hatchery release on May 21. Nonrandom lengths of Chinook in the migration confound the analysis of potential effects of hatchery salmon on the growth of natural Chinook salmon in 2005.

We tested the hypothesis that prey weight (% body weight) in natural subyearling Chinook salmon in the Transition Zone declined during the large release of hatchery Chinook salmon on May 21. Consumption of prey was not statistically lower after May 21. It is noteworthy, however, that consumption was consistently low in the three week period when subyearling Chinook salmon abundance was high. Prey availability in 2005 appeared to be relatively high (based on overall high growth and large fish size), possibly in response to warm temperature, low flows and low natural Chinook abundance.

Residence Time in Middle and Lower Green River

A model was developed to approximate residence time of natural Chinook salmon between the RM 34.5 trap and the lower study area. Residence time between RM 34.5 and RM 1-8.5 was approximately 8 days during early February, increasing to 13 days in mid-February, and to 25 days during late February to mid-April (range: 19 – 32 days). Residence time after mid-April was not estimated in 2005 because model assumptions were violated, but an otolith study indicated residence times declined after late May.

Conclusions

- Results in 2005 were consistent with previous studies that indicated densities of subyearling Chinook salmon were higher in the Transition Zone (RM 6.5 to at least RM 4.6) compared with adjacent reaches such as the lower estuary. However, lower river habitats also supported large catches of fingerling Chinook salmon during late March through early July. This shift in habitat utilization may reflect different behavioral responses of Chinook fry versus Chinook fingerlings to salinity.

- Data collected in 2005 and in previous years suggest that priority should be given to restoration projects in the Transition Zone and lower Duwamish River, if possible. While restoration projects in the lower estuary will provide benefits for juvenile salmon, available data suggest that juvenile salmon migrate through this reach relatively quickly and spend relatively little time in off-channel habitats.

- Densities of subyearling salmon were significantly greater in off-channel habitats compared with mainstem habitats located in the lower river, but significantly less in off-channel habitats in lower estuary. This pattern may reflect behavioral differences of Chinook inhabiting freshwater vs. marine habitats. This finding suggests that restoration projects in the lower river should focus on construction of off-channel habitats, whereas projects in the lower estuary might focus on projects along the mainstem.

- Habitats having gentle intertidal gradients and lower velocities tended to support higher Chinook densities. Bank armor and restoration of upper tidal and upland areas were not associated with higher catches. These findings suggest that restoration of salmon habitat should maximize additional intertidal habitat while providing fringe marsh and upland habitat to support prey production.

- Surface area of restored habitats should be maximized in order to support the large numbers of natural and hatchery salmon. Ideal habitats appear to be large areas having gentle intertidal mudflat slopes that are protected from currents while also providing refuge in a channel during low tides.

- Natural subyearling Chinook salmon were considerably more abundant in nearshore compared with mid-channel habitats of the Duwamish estuary during late January and February. This finding provides evidence that restoration projects should focus in nearshore areas.

- Chinook size and growth rate were greater in 2005 compared with previous years because water temperature was high, water flows were low, and juvenile Chinook abundance was low.

- Consumption of prey by Chinook salmon was consistently low during three weeks when hatchery salmon were highly abundant in the lower river and estuary, but low feeding also occurred prior to the arrival of hatchery Chinook salmon. This pattern confounded the analysis to evaluate whether hatchery salmon influenced feeding rates of natural Chinook salmon.

INTRODUCTION

An important goal of salmon recovery efforts in the Puget Sound region is to identify and implement habitat rehabilitation projects that will effectively enhance the viability of Puget Sound Chinook salmon (Shared Strategy 2005). However, prior to implementing these projects, information is needed on how and where Chinook salmon utilize existing habitats and whether specific habitat features are beneficial to Chinook salmon.

Research in the Duwamish River during 2002 and 2003 indicated densities of juvenile Chinook salmon and other salmonids were relatively high at the Turning Basin (RM 5.5) and Trimaran (RM 6.5) areas compared with areas farther downstream in the estuary (Nelson et al. 2004). It was hypothesized that fish aggregate in this reach of the Duwamish, called the "Transition Zone", because it is the area where freshwater significantly mixes with marine water and because large eddies with shallow, slow-moving water develop here. However, only two sites in this area were regularly sampled and the upstream and downstream high salmon density boundaries have not been identified.

Identification of boundaries surrounding high salmon density near RM 5.5 to RM 6.5 was identified as a top priority by the WRIA 9 Research Framework and the WRIA 9 Technical Committee because rehabilitation projects might be most beneficial if they target areas where Chinook salmon are known to aggregate (Ruggerone et al. 2004). It is also desirable to have additional data supporting or refuting the Transition Zone hypothesis and to have data that identifies habitat features selected by juvenile Chinook salmon. If fish do not prefer a specific reach, such as the Transition Zone, then habitat rehabilitation projects might be selected anywhere along the Duwamish River and estuary where favorable habitat conditions might be developed. In this case, information on specific habitat characteristics selected by Chinook salmon is especially desirable for habitat rehabilitation planning.

Body growth of salmon is an important determinant of Chinook salmon survival, therefore consideration of the potential for habitats to support salmon growth is an important component of habitat rehabilitation. Larger salmon are more likely to avoid predators and larger salmon may have greater probability of surviving winter when prey availability is low (Beamish and Mahnken 2001, Nagasawa 2000). Recent research of coded-wire-tagged (CWT) Chinook salmon indicated their survival declined 62% when their growth in Puget Sound and the lower Strait of Georgia was reduced in response to competition with juvenile pink salmon (Ruggerone and Goetz 2004, Ruggerone and Nielsen 2005). Furthermore, analyses of annual growth of salmon at sea since the 1950s indicated that the large increase in salmon abundance in northern regions since the mid-1970s was related to greater growth during early marine life (Ruggerone et al., in review).

Juvenile Chinook salmon may experience low growth rates in the Duwamish in response to 1) highly altered habitats, 2) a relatively small area of estuarine habitat, and 3) release of more than 3 million hatchery Chinook salmon that compete for prey and space. Research in 2003 suggested growth of Chinook salmon in the Duwamish was reduced during periods of high Chinook densities (Nelson et al. 2004) and that residence time of Chinook salmon in off-channel habitats significantly declined when numerous hatchery salmonid were released into the watershed (Ruggerone and Jeanes 2004). Although these studies support a logical hypothesis, there still is uncertainty whether competition for prey and space occurs annually. This uncertainty stems from 1) observations made in only one year (2003), and 2) the assumption that change in salmon size over time was due to growth rather than non-random movements of fish sizes through the study area.

Duwamish research results led to two broad questions that were addressed during the 2005 sampling season:

1) *What are the distribution patterns of juvenile salmon between RM 1 and 9 throughout the outmigration period, and how do these patterns correspond to physical habitat conditions (e.g., salinity, temperature, slope, substrate, bank type)?*

2) *What are the growth and feeding rates of juvenile Chinook salmon, and is habitat capacity sufficient to support high growth during periods of high salmon abundance?*

Null hypotheses and alternative hypotheses that stem from these questions are:

<u>Salmon Distribution:</u>

Ho: Distribution of Chinook salmon is random and not dependent on reach, tide stage, habitat characteristics, time period, or stock origin (natural vs. hatchery produced).

H_{A1}: Distribution of Chinook salmon is not random and Chinook densities are highest in a specific <u>reach</u> such as the transition zone (~RM 5.5-6.5) and this pattern is consistent over time; i.e., for both fry and fingerlings.

H_{A2}: Distribution of Chinook salmon is not random and Chinook densities are highest in <u>specific habitats</u> that can be characterized by habitat slope (gradient), bank type (natural, unnatural), rehabilitated site (yes, no), eddy potential (yes, no), salinity, temperature, velocity, and tide stage (ebbing, flooding, slack).

H_{A3}: Distribution of Chinook salmon is not random and Chinook densities are highest in a specific reach (H_A) <u>and</u> specific habitat characteristics of this reach (salinity, velocity, intertidal gradient, etc.) support highest densities.

H_{A4}: Distribution of Chinook salmon is not random and Chinook densities are higher in off-channel habitats compared with main channel habitats.

Salmon Growth:

Ho: Growth and prey consumption of subyearling Chinook salmon remain stable and moderately high throughout study period.

H_A: Growth and prey consumption of subyearling Chinook salmon decline significantly during periods of high Chinook (and other fish) densities.

The objective of this investigation was to test the above hypotheses in a effort to provide information that could be used by planners to restore salmon habitat and help recover Green/Duwamish Chinook salmon populations.

METHODS

Study Area

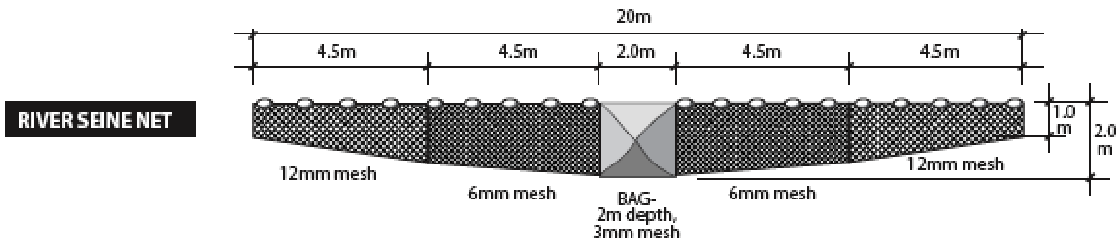
Primary sampling sites occurred from the Codiga Farm (Codiga) restoration site (RM 8.5) that was constructed by the US Army Corps of Engineers in 2004 downstream to Kellogg Island (RM 1) (Fig. 1). Aerial photographs of each sampling are shown in Fig. 2. The sampling area encompassed the lower Duwamish River where tides influence river elevation but have little effect on salinity (RM 6.6-8.5) (Dawson and Tilley 1972), the Transition Zone area where freshwater water begins to significantly mix with marine water (~RM 5.5 to RM 6.5), and the lower Duwamish estuary. The river channel upstream of the Turning Basin (RM 5.5) is relatively narrow and shallow (except for large eddy at RM 6.5), and the steep constructed banks are covered with vegetation. The channel broadens considerably at the Turning Basin, which is the upstream end of the highly industrialized Duwamish Waterway (TerraLogic 2004). The Duwamish Waterway is called the lower estuary in this report. The Duwamish Waterway is regularly dredged in order to maintain depths for large ships. A narrow band of intertidal mud habitat occurs adjacent to the dredged channel. Pre-history characteristics of the Green and Duwamish rivers described by Collins and Sheikh (2005) show that the existing Duwamish estuary has little resemblance to its original state and estuarine habitat is now much smaller because intertidal mudflats, wetlands, and sloughs have been lost.

Additional fish data were obtained from the WDFW fish trap (RM 34.5) where WDFW counts and measures juvenile salmon as they migrate downriver. Hatchery salmon are primarily released into Big Soos Creek (RM 34 of the Green River), Crisp Creek (RM 40), and upstream of Howard Hanson Dam (RM 64.5) (Fig. 1).

Fish Sampling

An initial task was to locate suitable river beach seine sampling areas upstream and downstream of the Transition Zone. A reconnaissance survey was conducted in early January to identify potential sampling sites in addition to sites that had been used in previous years. A total of 15 sites were identified, but one site was eliminated from consideration because permission was not granted from the land owner (i.e., shallow cove at RM 2). Sampling sites and their habitat characteristics are shown in Table 1. These sites include eight areas that were relatively close to the Transition Zone, four sites that were downstream, and three sites that were upstream. The sites selected for sampling included essentially all available areas that could be sampled by beach seine within the study area. Moored boats, vertical banks, and debris limited the availability of sampling sites in the estuary downstream of Transition Zone, whereas steep mud banks, debris, and swift current limited the availability of sites upstream of the Transition Zone.

A river seine was selected as the primary gear to sample fishes in nearshore river and estuarine habitats. The river seine was successfully used by Nelson et al. (2004) to sample fishes in the Duwamish River during 2001-2003. The river seine was selected over the Puget Sound Protocol (PSP) net because the river seine could be fished in relatively rapid current, and multiple sets could be sampled in the relatively small areas of available habitat. The river seine is 20 m long and up to 2 m deep. The wings have 6 -12 mm mesh and the bag is 3mm mesh.



Source: Nelson et al. (2004)

Nelson et al. (2004) describe deployment of the river seine in detail. The river seine differs from the PSP net because the river seine does not have 100' lines that extend the net offshore. The upstream end of the river seine is towed downstream at the same speed of the river current while the boat carries the lower end of the net downstream. The river seine samples approximately 33 m of shoreline (approximated (33 paces) by the biologist that receives the downstream end of the net). Thus, the river seine samples fish that are relatively close to shore, i.e., the area where subyearling Chinook salmon are likely to be most abundant (see mid-channel tests below). Surface area sampled by the river seine (approximately 400 m^2) was fairly consistent from site to site, except for Codiga Inside where the small cove reduced the surface area of the net by approximately 50% (note: catches were not adjusted for this bias).

Each site was sampled each week with the river seine from February 3 to July 12, 2005. Sampling typically occurred on Tuesday of each week. Two boat crews (3 or 4 people each) conducted the sampling effort. Sampling methodology by the two crews was standardized during a training field day in January. The goal was to sample each of the 14 sites up to three times per visit (providing up to three samples each week), but the limited size of some sites reduced the number of adjacent sets that could be made each week.

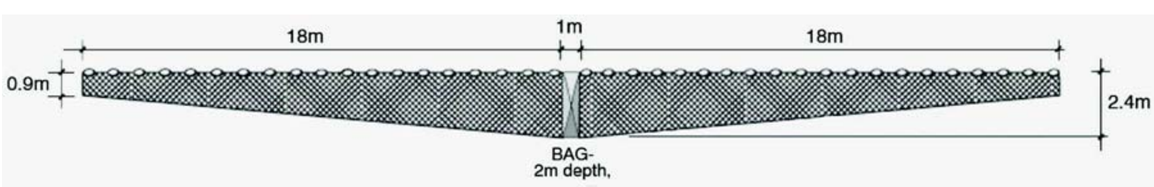
Immediately after capture, all fishes were placed in buckets of water, which were aerated if needed. All salmonids were identified to species; other fish were identified to species or genus, and all fish were counted. At least 30 salmon of each species, age (subyearling, yearling), and stock (natural, hatchery) were measured to the nearest mm (fork length). Measured fish were anesthetized with MS-222 (Tricaine Methanesulfonate) in approximately 40 mg/l solution, then allowed to recover in an aerated bucket prior to release. Approximately 10 Chinook salmon from each 10 mm length interval (~30-150 mm) were weighed during each two-month period in order to develop a length-weight relationship. Hatchery salmon were identified by the presence of an adipose fin clip, coded-wire-tag (CWT), or both. A CWT wand detector was used to identify fishes having a CWT. Only Chinook salmon and steelhead were mass marked (adipose fin clip) prior to release by the hatcheries. Estimates of unrecognizable fin clips among hatchery Chinook salmon were made by the study team who sampled marked fish in hatchery ponds immediately prior to release.

At the Turning Basin and Kellogg Island sites, up to 10 natural and 10 hatchery subyearling Chinook salmon were retained each week for stomach and otolith analyses. Samples were labeled so that stomach contents and otolith contents could be linked to each site. Fish stomachs were preserved in 10% formalin and they were analyzed at the University of Washington (see Cordell et al. 2006). Prey were identified, counted, and weighed to the nearest 0.0001 g. Otoliths, which were not removed from the fish, were preserved in ethanol and are stored at King County Department of Natural Resources until funds become available to examine otoliths in order to estimate daily growth and residence time of Chinook salmon in the estuary (Ruggerone and Volk 2004).

Additional Fish Sampling

Additional sampling of fishes in the Duwamish estuary was used to test specific hypotheses involving 1) presence and abundance of salmonids in the Duwamish during winter, and 2) density of Chinook salmon and other fishes in mid-channel versus nearshore areas of the estuary. This effort was conducted by members of the study team in conjunction with SAIC, Inc. and the Army Corps of Engineers, who funded the project. F. Goetz (ACOE) and C. Hunt (SAIC et al. 2004) provided data.

Nearshore areas of the Duwamish estuary were sampled with the PSP beach seine on a weekly basis from December 3, 2004 to March 3, 2005. Five sites were sampled (Trimaran, Turning Basin, Hamm Cr, Pit Bull, Kellogg East), all of which were sampled with the river seine beginning in February. The PSP seine is 37 m long and up to 2 m deep. Mesh size of the wings is 4 mm and mesh size of the bag is 2 mm knotless web. A 30 m line is attached to each end of the net. The net is set approximately 30 m offshore, then pulled into shore via the lines. The PSP seine sampled a surface area of approximately 520 m^2 (5,597 ft^2) or approximately 1.3x that of the river seine. Fish samples were processed as described above except otoliths and stomach contents were not obtained.



Source: Nelson et al. (2004)

Fishes in the mid-channel of the Duwamish estuary were sampled by purse seine on a weekly basis from December 4, 2004 to February 21, 2005. Up to five sites were sampled each week (Turning Basin, Hamm Cr area, C-Flats area, Pit Bull, Kellogg East). The purse seine is 230 m long x 18 m deep (750 x 60 ft) and constructed with multiple mesh sizes (SAIC et al. 2005). The net consisted of 25 mm mesh at the leading wing, 11 mm mesh in the center of the net, and 3 mm mesh at the last 30 m of net (collection bag). The net was deployed by the commercial purse seining vessel F/V Chasina (power block seiner) in a fashion to enhance capture of downstream migrating fishes. Although an actively fished net typically leads smaller fish into the smaller-mesh bag, a member of the study team periodically examined the pursed net for potential small salmonids escaping through the mesh (none observed). The approximate surface area fished by each purse seine set was 1.03 acres (0.42 ha) or approximately 8x the PSP net. The net fished the entire water column of the Duwamish (net dragged on bottom) and it typically spanned the entire dredged channel.

Water Quality and Environmental Conditions

Water quality data were collected at each site during each week when sampling for fishes. Water temperature, salinity, and dissolved oxygen were recorded at the surface and at each 2.5 ft depth interval down to the bottom within the seining area (typically 5 ft or less). Secchi depth, which measures water clarity, was measured. Water velocity within the seining area was visually approximated. Tide stage (ebb, flood, slack low, slack high) and tide elevation from the gage at 8th Avenue South were obtained from projections by Nautical Software. Monthly air temperature and precipitation data since 1950 were obtained from SeaTac airport (http://www.wrcc.dri.edu). Daily Green River discharge at the Auburn gage (12113000) since 1935 was obtained from the US Geological Survey (http://waterdata.usgs.gov/nwis).

Temperature recorders were deployed at six sampling sites and were programmed to record temperature every hour. The thermographs were attached to the substrate near 0-2+ ft MLLW. However, at the Turning Basin and Kellogg West, thermographs were suspended from a float to record temperature at the surface and depths of 2.5 ft, 5 ft, and the bottom. Temperature recorders were exposed to air temperatures during low tides, therefore hourly tide stage data, hourly air temperature, and abrupt changes in temperature were used to identify and remove values that measured air temperature rather than water temperature.

Data Analysis

Data collected during the field season were entered into an Excel workbook. All data entries were checked by another person. Catch and size data were organized by statistical week, which begin on Sunday and end on Saturday, except for the first week. Statistical week 1 began on January 1, 2005 (Saturday). Statistical week 2 began on January 2, 2005.

Catch and size values were reported as weekly mean values ± 1 standard error unless noted otherwise (e.g., standard deviation). Statistical analyses of catch estimates utilized a log transformation in order to normalize the distribution of catches, a required assumption of statistical analyses. Thus, some data are described as geometric means (g.m.) in which variability around the reported geometric mean is asymmetrical. A geometric mean is typically less than an arithmetic mean.

Statistical analyses were conducted to test specific questions. Regression analysis was used to determine correlation between two variables. Analysis of variance (ANOVA) was used to test for differences in mean values, such as catch in the Transition Zone versus the lower river and lower estuary. These are basic statistical tools that are described in most statistics books (e.g., Zar 1996). A key term that describes the statistical significance of a test is the P value. Typically, a P value < 0.05 implies statistical significance, i.e., the null hypothesis (H_0) is rejected and the values are statistically different (ANOVA) or two data series were correlated (slope of a regression was > 0). The P value indicates the probability of rejecting a null hypothesis when in fact it should not have been rejected (i.e., no difference between two values).

Some fish density and fish length data collected during December 2004 through March 2005 were obtained from PSP seine catches rather than the river seine. Statistical analyses involving catch per effort only utilized river seine data in order to prevent biased catch estimates.

RESULTS AND DISCUSSION

Flow and Temperature

Daily flows in the Green River were typically below average during the 2005 water year (October 2004 to September 2005) compared with the historical mean (Fig. 3). The 2005 water year corresponded with the 2004 Chinook parent spawning year (brood year), in which Chinook spawned during fall 2004, then emerged from gravel, reared in the river, and migrated to Puget Sound prior to July 2005, or so. On average, mean daily flows were 35% less than the historical mean from November 2004 to June 2005. Flows were below average during each month, but they were exceptionally low during February and March 2005 (65-71% below average). Peak monthly flows were 33% below average. All peak monthly flows were below average except for January 2005 (55% above average) when flow was exceptionally high and reached 8,420 cfs on January 19. Minimum monthly flows were below average during each month, but they were exceptionally low during January through March.

Monthly mean air temperatures recorded at SeaTac Airport during October 2004 to June 2005 were above average compared with temperatures since 1950 (Fig. 4). However, air temperatures during 2005 were typical of above average values that have consistently occurred since the mid-1970s.

Monthly mean precipitation recorded at SeaTac Airport from October 2004 to March 2005 was below average compared with precipitation since 1950, but precipitation was above average during April through June (Fig. 5). Thus, precipitation was low during the fall and winter months when most precipitation occurs and many Chinook are still in the gravel, but slightly above average during spring and early summer when precipitation is typically less.

Water temperature in the upper water column was measured hourly at six of the sampling sites from February 12 to July 12, 2005 (Fig. 6). At RM 7.5 and RM 8.5, where there is relatively little mixing with marine water, temperature was relatively cold (4°C) in February, then increased steadily over time to approximately 12°C in early May and to 15°C in June.

Temperatures sampled from Kellogg Island (RM 1) to the Turning Basin (RM 5.5) were influenced by both fresh and marine waters. During February, marine waters were warm compared with fresh water. Beginning in mid-April, marine waters were cooler than fresh water and the diel range in temperatures at each location was relatively great (daily range: 7°C). The stable lower range in daily temperature was likely established by the relatively stable temperature of marine water. Water temperature in Elliott Bay varied relatively little during the day (Fig. 6).

Water temperature was recorded at several depths at both the Turning Basin and Kellogg Island sampling sites (surface, 2.5 ft, 5 ft, bottom). Temperatures at each depth tended to be highly correlated (Fig. 7). However, during February, surface waters tended to be colder than deeper waters (~2°C less). After mid-April, surface waters tended to be relatively warm (up to 3°C).

Water quality data were obtained at each sampling site while sampling for fishes (Fig. 8). Mean salinity at a depth of 2.5 ft decreased from 12 ppt at RM 1 (Kellogg Island) to 5 ppt at RM 3.5 (Pit Bull) to approximately 3.5 ppt in the lower Transition Zone (RM 4.6-5.5) to approximately 1 ppt in the upper Transition Zone and lower River (RM 6.3 to 8.5). Dissolved oxygen (2.5 depth) was adequate for salmon in all areas, but the lower estuary and lower Transition Zone tended to have lower dissolved oxygen (8.2-9.5 mg/l) compared with the upper Transition Zone and lower river (10-11.5 mg/l). Surface water temperature was similar throughout the study area. Water clarity (Secchi depth) was greatest in the lower estuary (9.5 ft) compared with upstream areas (7 ft). Water velocity, which was approximated from visual observations within the seining area, was relatively low in the lower river and lower Transition Zone compare with upstream areas. Mean tide height during at each site during sampling ranged from +3.5 ft to +6.7 ft (MLLW), averaging 5.2 ft. Tide height tended to be relatively high during sampling of the lower estuary and Codiga and slightly lower in the lower Transition Zone areas.

Overview of Fish Sampling Efforts

Fishes in 14 littoral areas of the Duwamish River and estuary were routinely sampled each week by river seine from February 3 to July 12, 2005. Although the goal was to sample each site three times per week, some areas were too small to allow for repetitive sampling, e.g., Codiga Inside, Tukwila Bridge, Spawner Beach, Sabey, and Pit Bull (Table 2). On average, 2.6 river seine sets were made at each site per week for a total of 896 sets during the study period. Additionally, 18 sets with a PSP seine net were made at the USFWS study site located immediately upstream of the Turning Basin site. Catches from the PSP seine were excluded from statistical analyses involving catch rates with the river seine.

Data from a Seattle District Army Corps of Engineers (ACOE) project were included in the analyses when examining onshore/offshore distribution of salmon and presence of salmon during winter (SAIC et al. 2004). The ACOE project sampled each of five sites approximately 2.9 times per week from December 4 to March 3 (Table 2). These sites were sampled with the PSP beach seine and approximately 50% of the effort occurred at night. Additionally, 88 sets were made with the 700 ft long x 60 ft deep purse seine from December 4 through February 25. Members of the study team assisted with the ACOE effort.

Seasonality of Fishes in Littoral Zone

Subyearling Chinook salmon

The WDFW sampled downstream migrating juvenile salmonids at the RM 34.5 screw trap from January 10 to July 15, 2005 (P. Topping, WDFW, pers. comm.). Small numbers of subyearling natural Chinook salmon were captured during the first week of sampling in mid-January (<10 fry per night), increasing to approximately 250 fry per night on January 21 (Fig. 9); i.e., the first night of sampling after the high water event. Chinook catches continued to increase until peaking in early March (630 per night), then catches declined rapidly to <10 fry per night during early April to mid-May. A minor second peak occurred from mid-May to late June, averaging 36 subyearling natural Chinook per night. Thus, juvenile Chinook emigrating from the middle Green River exhibited a bimodal migration pattern with a relatively small second mode of fingerling Chinook, a pattern that has been previously observed in recent years (Nelson et al. 2004). Estimates of total Chinook migrating from RM 34.5 are not yet available, i.e., values expanding trap counts to total migration counts.

One subyearling natural Chinook salmon was captured by beach seine in the estuary at night on December 23, 2004. However, Chinook fry were not regularly captured in the lower river and estuary until the nighttime sampling effort on January 20 (3.1 fry per set), which followed exceptionally high flows that began on January 18 (6,000 cfs) and peaked on January 19 (8,420 cfs). Approximately four to six fry were captured per set from late January to early February (Fig. 9). Catch rates declined slightly during mid- to late February as flows subsided (Fig. 3), then increased to approximately five fry per set in mid-March even though flows remained low. The smallest catches of the season occurred during mid-April (0.1 fry per set), then catches increased to approximately two fish per set from late April to late May before steadily declining throughout June and early July. The temporal pattern of abundance was not strongly bimodal, as observed in previous years and in the RM 34.5 trap.

Approximately 0.57 million subyearling hatchery Chinook salmon were released above Howard Hanson Dam during March 10-25, and 3.4 million subyearling Chinook were released from the WDFW hatchery (Soos Cr) during May 21-June 2 (Tables 3 and 4). Sampling of 6,958 untagged Chinook in all WDFW hatchery ponds on May 9 indicated 4.13% of the Chinook received unrecognizable fin clips and would have been identified as natural salmon if captured by seine gear in the lower river (Table 5). Thus, approximately 141,000 subyearling hatchery Chinook salmon were unmarked and would have been identified as natural salmon if captured.

Small numbers of subyearling hatchery Chinook salmon were present in the lower river and estuary beginning in late March (Fig. 9), suggesting that some fish escaped through Howard Hanson Dam prior to the spring reservoir refill period. Approximately one hatchery Chinook per set was captured from late April to mid-May, i.e., the period prior to the WDFW release of Chinook salmon into Soos Creek. Hatchery Chinook were exceptionally abundant in the lower river and estuary from late May to early June, averaging 18 to 28 fish per set (Fig. 9). Catches decline sharply from mid-June to early July.

Although the number of hatchery Chinook salmon captured in the lower river and estuary was small prior to the large release from the WDFW hatchery, the percentage of hatchery salmon among subyearling Chinook salmon was large. During eight weeks prior the WDFW release of hatchery Chinook in mid-May, the percentage of hatchery salmon in the catch averaged 29% (Fig. 10). During this period, the percentage of hatchery salmon was greatest in the Transition Zone (avg. 38%), followed by the lower river (26%), and the lower estuary (14%) (Fig. 10).

The percentage of subyearling Chinook represented by hatchery salmon averaged 89% from mid-May to the end of sampling in early July (Fig. 10). The high percentage of hatchery salmon was consistent among all locations, including the lower river, Transition Zone, and lower estuary. Thus, hatchery salmon dominated the catch of Chinook salmon from mid-May through the remaining migration period of juvenile Chinook salmon.

We compared catch per effort of subyearling natural and hatchery Chinook salmon during 2002, 2003, and 2005. Mean catch per week of natural Chinook at the WDFW trap at RM 34.5 was nearly identical during each year (range: 109 to 111 Chinook per night) (Fig. 11). However, catches of natural Chinook in the lower river and estuary during 2005 were approximately 75% lower than in 2003 and 15% lower than in 2002. In 2002, the second mode of migrating Chinook (late May and June) was considerably larger than that in 2003 and 2005, but the abundance of early migrating Chinook in 2002 was low. Catches of hatchery Chinook in 2005 were nearly identical to that in 2003, but they were approximately 66% lower than in 2002. Thus, catches of natural subyearling Chinook salmon in the lower river and estuary were low in 2005 compared with catches in recent years.

Parent spawning escapement in 2004 (13,991 spawners), which produced juvenile Chinook in 2005, was greater than all annual escapements since at least 1989. It was 15% greater, on average, compared with that in 2002 and 2003 and 140% greater than the current escapement goal of 5,800 spawners (T. Cropp, WDFW, pers. comm.). Chinook spawners appeared to be crowded in 1999, 2002, 2003, and 2004 (i.e., > 10,400 spawners), especially in pool tail-out areas where Chinook frequently spawn. The large escapement in 2004 might have led to low production of juvenile Chinook in 2005, but more research is needed to evaluate this hypothesis because peak flows in late January might have also contributed to reduced Chinook catches.

<u>Other Salmonids</u>

Naturally produced yearling Chinook salmon (unmarked, non-tagged) were present in the lower river and estuary primarily from late March to late April (Fig. 9). Catches were small (<0.3 fish per set).

Approximately 200,000 yearling hatchery Chinook salmon were released from Icy Creek ponds during May 3 to May 13. A number of yearling hatchery Chinook were captured prior to the release period (Fig. 9), e.g., 15 yearlings were captured at RM 2.0 (Gravel Beach) on April 26. These fish could have originated from other watersheds, escaped from the rearing pond in 2005, or over-wintered after release as subyearlings in 2004. Less than 0.5 yearling Chinook were captured per set during the release period, indicating yearling hatchery Chinook salmon rapidly migrated through the lower river and estuary.

Small numbers of yearling and older hatchery Chinook salmon were consistently captured in RM 1.0 to RM 5.5 from early December 2004 to late January 2005 (Fig. 9). Most of these fish were large (>200 mm) and may have originated from other watersheds. Catches of naturally produced yearling Chinook were insignificant during this period.

Approximately 2.4 million chum fry were released from the Keta Creek Hatchery during late March and April. No hatchery chum were marked, therefore hatchery chum could not be distinguished from natural chum salmon during the period they co-inhabited the study area. Small numbers of natural chum fry were present from late February to mid-March (avg. < 1 per set) (Fig. 9). Chum abundance increased sharply during late March to early May when hatchery chum were present (avg. 90 per set), then declined rapidly into early July.

Approximately 1 million yearling and 744,000 subyearling hatchery coho salmon were released into the Green River and tributaries during late April and early May (Tables 3 and 4). Yearling coho released from the WDFW hatchery were mass-marked, whereas only approximately 20% of the 240,000 yearling coho released from the MIT hatchery were marked. None of the subyearling coho salmon were marked. Thus, natural coho salmon could not be distinguished from hatchery coho salmon. Abundances of marked and unmarked yearling coho salmon peaked during a brief period in early May, then declined sharply (Fig. 12). Most catches of coho salmon tended to occur within one or two sets during a given week, indicating coho were aggregated rather than distributed throughout the sampling areas. The rapid decline in yearling coho during May indicated that most coho likely spent less than a week or so in the lower river and estuary. Few subyearling coho salmon were captured in the lower river and estuary.

Natural steelhead trout (> age 1) were captured in small numbers (0.1 ± 0.5 fish per set) from mid-February to mid-May. Approximately 429,000 marked hatchery steelhead were released during May 1 to May 13 (Table 3). Most hatchery steelhead were captured during the release period and all steelhead were captured during May (1.9 ± 10 fish per set). The small catches suggest that steelhead rapidly migrated through the lower river and estuary.

No bull trout/Dolly Varden char were captured in the lower river and estuary from December 2004 to mid-July 2005.

<u>Non-Salmonids</u>

Shiner perch was the dominant non-salmonid captured by beach seine gear. Essentially all shiner perch were captured at and downstream of RM 6.5 (Trimaran), i.e., the area of significant marine water influence. Shiner perch were not abundant in littoral areas until early June (Fig. 12). Relatively large catches of shiner perch occurred from early December through early January, but these catches were made by the PSP seine which extends further offshore compared with the river seine that was used from February though early July. Purse seine catches indicated shiner perch were highly abundant in mid-channel areas from December through at least mid-February.

Total catch of fishes were relatively great from April through mid-May (Fig. 12). This period corresponds with the presence of numerous chum salmon fry, which typically was the most abundant species in the littoral zone.

Transition Zone Hypothesis

Natural Subyearling Chinook Salmon

Subyearling natural Chinook salmon data were grouped into three time periods corresponding with 1) the seining period when numerous fry were captured at the RM 34.5 trap (February 3 to March 21), 2) the period when few fry were captured in the trap but catches of natural Chinook salmon in the river seine were relatively high (March 28 to May 16), and 3) the period when both natural and hatchery Chinook salmon were present (May 23 to July 12).

A two factor ANOVA (Location, Period) indicated densities of subyearling natural Chinook salmon were significantly different between locations and time periods (Table 6). Highest catches occurred at RM 4.7 (C-Flat station) and nearby locations (RM 5.5 (Turning Basin), RM 5.2, and RM 4.6) (Fig. 13). Relatively high catches also occurred inside the Codiga restoration site (RM 8.5). Lowest catches of subyearling Chinook salmon occurred along the west side of Kellogg Island (RM 1), east side of Kellogg Island, RM 2.3, RM 6.3 and RM 7.0. Multiple range statistical tests, which identify statistical differences between each location, are summarized in Table 7. The Appendix provides graphs of weekly Chinook catches at each site.

ANOVA tests support the hypothesis that densities of subyearling Chinook salmon are relatively great in the Transition Zone area where fresh water first meets marine water. The analysis also shows that the Transition Zone extends downstream from Trimaran (RM 6.5) to at least RM 4.6. In contrast with previous years, catches were not especially high at RM 6.5, which is the first area of the Transition Zone where Juveniles typically encounter brackish water (Fig. 13). Chinook catches were relatively low in the lower estuary region (RM 1.0 to 2.3), including Kellogg Island and a nearby site (Gravel Beach). It is noteworthy that the two locations in the upper study area having the lowest catches were sites where nearshore water velocity was relatively high (i.e., RM 6.3 and RM 7.0).

A second two factor ANOVA (Zone, Period) was conducted after grouping locations into three zones: 1) lower river (RM 6.8 to RM 8.5), 2) Transition Zone (RM 4.7 to RM 6.5), and 3) lower estuary (RM 1 to RM 3.5). ANOVA and multiple range tests indicated Chinook catches were significantly greater in the Transition Zone compared with either the lower river ($P = 0.038$) or the lower estuary ($P < 0.001$) (Fig. 14, Table 6). Chinook catches in the lower river were not statistically greater than those in the lower estuary but they were markedly higher, on average ($P = 0.070$), except in February and March..

The interaction terms of the two factor ANOVAs (Location x Period; Zone x Period) were statistically significant (Table 6), indicating Chinook catches were not consistently high or low at respective locations and zones during each of the three periods. During February to mid-May, Chinook catches in the Transition Zone were higher than those in the river and estuary (Fig. 14). From late May to early July, catches of Chinook fingerlings were significantly greater in the lower river compared with the Transition Zone (multiple range test, $P < 0.05$), suggesting that late season migrants (fingerlings) may hold in the lower river then move through the transition zone relatively rapidly. During late January to late March, catches of Chinook fry in the lower estuary were significantly greater than those in the lower river ($P = 0.032$). Thus, Chinook fry were most abundant in the Transition Zone, whereas Chinook fingerlings were most abundant in the lower river.

Chinook catches in the Transition Zone were greater than catches in the lower estuary (RM 1-3.5) during each of the three time periods. On average, catches in the Transition Zone were 57% greater during February 3 to March 21, 259% greater during March 28 to May 16, and 118% greater during May 23 to July 12 compared with catches in the lower estuary (RM 1 to 3.5) (Fig. 14). Thus, both Chinook fry and fingerlings were more abundant in the Transition Zone compared with the lower estuary.

Catches of natural Chinook salmon in the Transition Zone versus the lower river (RM 6.6 to 8.5) were 262% greater during February 3 to March 21, 16% greater during March 28 to May 16, but 39% less during May 23 to July 12. Relative abundances of Chinook salmon in the lower river increased over time, whereas abundances in the Transition Zone and lower estuary declined. During May 23 to July 12, abundance of natural Chinook salmon in the lower river was 260% greater than in the lower estuary.

Hatchery Subyearling Chinook Salmon

Subyearling hatchery Chinook salmon were more abundant in the lower river than in the transition zone and lower estuary (Fig. 13), however, there were too few hatchery salmon were present to examine their distribution prior to April, i.e. the time period when subyearling natural Chinook salmon were especially abundant in the Transition Zone. The Appendix provides graphs of weekly hatchery Chinook catches at each site.

ANOVA indicated catch rates of hatchery Chinook salmon were significantly different between the three zones (df = 2, 1, 419; $F = 7.614$, $P < 0.001$). Multiple range tests indicated catch rates of hatchery Chinook salmon were greatest in the lower river (g.m. 4.0 fish per set), followed by the Transition Zone (2.6 fish), and the lower estuary (1.55 fish) ($P < 0.05$). This pattern was consistent from late April to early July.

The combined distribution of hatchery and natural Chinook salmon was examined. ANOVA indicated statistical differences in catch rates by zone (df = 2, 2, 849; $F = 8.496$, $P < 0.001$). Multiple range tests indicated Chinook catch rates were greater in the Transition Zone (g.m. 2.2 fish per set) and the lower River (1.8 fish) compared with the lower estuary (1.2 fish) ($P < 0.05$) (Fig. 13). However, importance of each zone varied by period: the Transition Zone supported the highest catches of fry and fingerlings during late January to mid-May, whereas the lower river supported the greatest catches of fingerlings during late May to early July.

Chum Salmon

Catches of chum salmon did not vary significantly between the three zones (df = 2, 1, 391; F = 1.239, P = 0.291). On average, chum salmon catches tended to be somewhat greater in the lower estuary (g.m. 8.4 fish per set), followed by the Transition Zone (5.7 fish), and the lower river (3.3 fish). Chum salmon tended to be most abundant at the Turning Basin (RM 5.5) and most downstream areas (Fig. 13). This pattern highlights the tendency for chum salmon fry to migrate rapidly through freshwater to reach marine waters. The Appendix provides graphs of weekly chum catches at each site.

Yearling Salmon

Too few yearling salmon were captured throughout the study period to test whether yearling salmon were most abundant in specific areas. Yearling salmon were captured at most sampling locations (Fig. 13) and they appear to move through the study area relatively rapidly.

Habitat Feature Hypothesis

The habitat hypothesis states that Chinook salmon will be most abundant in habitats having specific conditions that are presumably most favorable for rearing salmon. The Transition Zone Hypotheses described above indicated that Chinook salmon were most abundant within a specific reach of the Duwamish, called the Transition Zone, i.e. approximately RM 4.6 to RM 6.5.

As an initial step to evaluate the habitat hypothesis, we categorized habitat features such as bank armor, substrate type, rehabilitation/natural, eddy potential, water velocity, slope of intertidal area, and salinity (2.5 ft depth) (Table 1). ANOVAs were performed for each time period (February 3 to March 22, March 28 to May 16, May 23 to July 12) and all season to determine whether abundances of natural subyearling Chinook salmon differed in response to levels within each habitat variable. Type of analysis does not control for all factors that may influence salmon abundance and the tests are subject to potentially confounding factors that may influence the results.

ANOVAs indicated no differences in abundances of natural Chinook salmon occupying habitats having armored vs. un-armored banks, rehabilitated or natural habitat features vs. highly altered habitat, and intertidal substrate type (Fig. 15) (df = 1, 851; P > 0.05). The lack of patterns occurred during each time period. During the early migration period, natural Chinook salmon tended to be more abundant in habitats that form eddies (P = 0.217) and that have relatively low water velocities (P = 0.139). Velocity and eddy formation tended to have less effect on Chinook salmon after late March.

Chinook salmon were statistically more abundant in low gradient intertidal areas (<4°) compared with higher gradient areas (9-16°) during both the early migration period (P = 0.005) and throughout the study period (P < 0.001) (Fig. 15). This finding might result from 1) lower water velocity, 2) larger surface area of shallow habitat, and/or 3) greater efficiency of the beach seine in low gradient.

Salinity (ppt) influenced the abundance of natural subyearling Chinook salmon within the study area. However, the effect of salinity on salmon abundance varied with season. During the early migration period (February 3 to March 22), Chinook salmon were more abundant in brackish water areas (>2 ppt) compared with freshwater habitats (<2 ppt) (Fig. 16) (df = 2, 282, P = 0.018). From late March to early July, Chinook salmon were more abundant in freshwater habitats (<2 ppt) compared with more saline areas (>5 ppt) (df = 2, 284, P = 0.002; df = 2, 278, P < 0.001). Abundance was intermediate in habitats having intermediate salinity. These findings are consistent with those described above in which the importance of the Transition Zone and lower river zone varied with season (Fig. 14). These findings provide evidence that early migrating Chinook fry (February to March) tend to rapidly move through the lower river (low salinity) and hold in the Transition Zone and other brackish waters, whereas later migrating fingerling Chinook tend to hold and rear in the lower river habitats, then move through brackish water areas relatively rapidly. In other words, early Chinook fry may actively migrate or be transported through the lower river to brackish waters where they try to hold before migrating to more saline waters, whereas fingerlings are sufficiently large to hold in the lower river, then migrate relatively rapidly through the brackish Transition Zone and lower estuary, in part because they are better prepared for saline water. In 2005, water flow and velocities were exceptionally low, suggesting that low catches of fry in the lower river prior to late March may have been related to active migration rather than displacement by high velocities. These findings indicate that the importance of habitat zones (lower river, Transition Zone, and lower estuary) varies with the life stage of Chinook salmon.

Multiple regression was used to further evaluate whether certain habitat characteristics tended to be correlated with catches of natural subyearling Chinook salmon. Habitat variables and channel conditions such as bank armoring (yes, no), eddy potential (yes, no), river zone (river, Transition Zone, estuary), and tide stage (flood, ebb, slack ebb, slack flood) were coded using dummy variables (e.g., 0 or 1) for potential input into the regression model. Continuous variables tested in the model included intertidal bank slope (°), water velocity (fps), river discharge at Auburn (cfs), tide height (ft), water temperature (°C), salinity (ppt @ 2.5 ft), statistical week, number of hatchery Chinook salmon, number of chum salmon, and number of shiner perch. Data from each site during each week were used in the analysis.

Number of natural Chinook salmon could be predicted from the following statistical model:

$$\begin{aligned}\mathrm{Log}_e\ \text{Chinook} = {} & .913 + .030\ (\text{Salinity})\ (\text{Period}) - .0.029\ (\text{Slope}) - .216\ (\text{Estuary}) \\ & - .101\ (\mathrm{Log}_e\ \text{Perch}),\end{aligned}$$

$R^2 = 0.08$, n = 854, overall F = 20.26, overall P < 0.001, variable P < 0.015. The model incorporates interaction between salinity and time period, i.e., Period is coded 1 during February 3 to March 22 and -1 during March 28 to July 12). The model suggests that natural Chinook catch rates were higher when 1) salinity was high during the early migration period, 2) salinity was low during the later migration period, 3) intertidal slope was low, sampling occurred upstream of the lower estuary, and when few shiner perch were present. The model suggests shiner perch might compete with Chinook salmon for resources (see Study 2 for more information about interactions with perch) and that catches tend to be relatively low in the lower estuary. However, further study is need to evaluate whether or not high densities of shiner perch affect Chinook feeding or rearing. Other habitat features, such as substrate type, bank armoring, restoration, eddy potential water velocity, and water temperature did not add statistically significant information to the model that describes Chinook abundance ($P > 0.05$). The statistical model is consistent with the ANOVAs described above.

A statistical model was also developed that incorporated hatchery Chinook salmon and chum salmon:

$$\begin{aligned}\text{Log}_e\ \text{Chinook} = {} & 1.376 + .017\ (\text{Salinity})\ (\text{Period}) - .0.029\ (\text{Slope}) - .190\ (\text{Estuary}) \\ & + .361\ (\text{H Chinook}) + .056\ (\text{Chum}) -.045\ (\text{week}),\end{aligned}$$

$R^2 = 0.23$, $n = 854$, overall $F = 44.38$, overall $P < 0.001$, variable $P < 0.002$. This model indicates that natural Chinook salmon tend to inhabit areas occupied by hatchery Chinook and chum salmon.

The Transition Zone supported the highest overall catches of subyearling Chinook salmon, as described previously. Within the Transition Zone, relatively small catches of Chinook salmon occurred at Sabey, whereas the greatest catches occurred at C-Flats (Fig. 13). Habitat at Sabey consists of a steep mud slope, natural bank with no armoring, and relatively high velocity during ebbing tides. The lack of shallow, low velocity habitat at Sabey (and some difficulty in setting the net) likely contributed to relatively low catches at this site. In contrast, C-Flats has a broad, shallow mud bench that remains wetted until approximately 0.0 ft MLLW (Fig. 1). Water velocity in this area was typically very low.

In previous years, the Trimaran site produced numerous Chinook salmon, but catches were relatively low in 2005. The reason for the low catches in 2005 are not known, but possibly it was related to the low flows in 2005 and the relationship between flow and the large eddy at the Trimaran site.

In the lower river, relatively small catches occurred at Tukwila Bridge (RM 7.0), whereas high catches occurred in Codiga Cove restoration site (RM 8.5). Habitat at Tukwila Bridge consisted of a steep, mud slope, some riprap, and blackberries. Little shallow water habitat was present and velocities were somewhat high. In contrast, Codiga Cove provided shallow habitat protected from the mainstem current. The bank was steep, reconstructed with riprap, and contained some emergent vegetation; the bottom was soft, low gradient, and contained large woody debris. The primary factor contributing to higher Chinook in the Codiga Cove compared with Tukwila Bridge was likely the availability of shallow, low velocity habitat. Snags occasionally interfered with seine sets at the Tukwila Bridge site, but these sets were discarded if the field crew believed that the snag interfered with catch efficiency.

Previous studies also have shown that relatively few Chinook salmon occur near Kellogg Island compared with upstream sites (Matsuda et al. 1968, Nelson et al. 2004) even though habitat quality at Kellogg Island seems to be relatively high for juvenile salmon, e.g., low velocity, shallow and large mud habitat. Catches were especially low along the west side of Kellogg Island, i.e., the side channel. Two key factors may have caused relatively few Chinook salmon to occupy Kellogg Island habitats, especially the side channel: 1) juvenile salmon may be migratory in the area of Kellogg Island compared with upstream areas of the Transition Zone, and 2) side channel habitat was dewatered at approximately 2-3 ft MLLW, forcing fishes to enter mainstem areas.

When evaluating the effect of habitat features on abundances of Chinook salmon, it is important to recognize that characteristics of monitored habitats in each zone were not equal. For example, steep intertidal slope tended to produce fewer Chinook salmon. Intertidal slope in the lower river (11.1° ± 4.5°) was markedly greater compared with that in the Transition Zone (5.4° ± 3.4°) and lower estuary (6.3° ± 1.9°) (Table 1). Fewer sites without rep-rap were available in the lower river compared with downstream areas. It is also noteworthy that highly modified shoreline areas, such as those with over water structures or boats, were not sampled in this survey.

Tidal exchange is a dynamic feature within the study area that influences characteristics of habitats. Statistical tests did not detect a significant effect of tide height (ft) or tide stage (flood, ebb, slack high, slack low) within the range of tides sampled. However, the effect of tides was not a controlled variable in this study. When preparing the study design we hypothesized that juvenile salmon may shift downstream during low tides compared with high tides. The effect of tides on distribution of fish could have been formally tested with paired sampling effort during negative tide heights, but sufficient funding was not available for this additional test. Instead, most sampling effort occurred during moderate tide heights (Fig. 8).

In summary, statistical tests and models indicated that juvenile Chinook salmon catches were largely associated with habitat zones (Transition Zone, lower river, lower estuary), salinity, and intertidal slope. However, the effect of salinity on Chinook abundance changed during the migration period: during late winter, Chinook salmon were most abundant in the brackish salinities of the Transition Zone compared with upriver sites. During April to July, Chinook salmon abundance shifted to low salinity areas associated with the lower river and the Transition Zone. We interpret these finding to indicate Chinook fry are carried downstream during late winter and attempt to hold in brackish waters before moving to Puget Sound, whereas fingerling Chinook salmon hold in the lower river and Transition Zone, then rapidly move through the more saline areas because they acclimate to more saline waters more rapidly than Chinook fry. Statistical tests also indicate that shallow, intertidal mudflats like contributed more to high Chinook densities compared with bank conditions.

Off-channel vs. Main Channel Salmon Hypothesis

We tested the hypothesis that densities of subyearling salmon are higher in off-channel areas compared with mainstem areas. This test utilized weekly river seine sampling at the Codiga restoration site (inside cove vs. mainstem) and Kellogg Island (side channel vs. mainstem). ANOVA identified a strong interaction between the two factors (location, channel area) indicating the effect of off-channel vs. mainstem habitat on salmon densities was different for Codiga and Kellogg Island (df = 1, 246, F = 7.393, P = 0.007). Salmon densities at Codiga (RM 8.5) tended to be higher in the off-channel site compared with the adjacent mainstem site, whereas salmon densities at Kellogg Island (RM 1.0) tended to be higher in the mainstem site. This pattern likely reflects the response of juvenile Chinook salmon to low salinity at Codiga compared with relatively high salinity near Kellogg Island. Therefore, separate tests were conducted for Codiga and Kellogg Island.

A two factor ANOVA (channel area, period) indicated that densities of subyearling salmon (natural and hatchery Chinook and chum fry) were significantly greater in Codiga Cove compared with the adjacent mainstem area ($df = 1, 100$; $F = 6.530$, $P = 0.012$). The off-channel area effect was consistent for all three time periods (Fig. 17), as indicated by the non-significant interaction term ($df = 2, 100$; $P = 0.259$).

It is noteworthy that higher densities in the Codiga off-channel area was consistent among each species during each time period except for natural Chinook during March 28 to May 16. During this period, chum fry tended to be exceptionally abundant in the cove compared with the other two periods. The high chum density in the cove might have caused more Chinook to rear outside the cove during this period. However, a shift in the distribution of natural Chinook salmon in the Codiga area was not apparent during late May and June when numerous hatchery Chinook were present.

In contrast to the observations at Codiga, a two factor ANOVA (channel area, period) indicated that densities of subyearling salmon were significantly greater along the mainstem area of Kellogg Island compared with the side channel area ($df = 1, 100$; $F = 6.530$, $P = 0.012$). The channel area effect was consistent for all three time periods (Fig. 17), as indicated by the non-significant interaction term ($df = 2, 100$; $P = 0.259$). The channel area effect was consistent for natural and hatchery subyearling Chinook salmon and chum fry.

These findings suggest behavior of subyearling Chinook salmon varies from the lower river to the lower estuary. In the lower river, juvenile Chinook salmon appear to seek low velocity areas, such as Codiga cove, rather than mainstem areas having higher water velocity. In the lower estuary, relatively few Chinook salmon entered the low velocity area west of Kellogg Island, possibly because Chinook are more migratory after leaving the lower river and transition zone. Conceivably, the lower catches west of Kellogg Island may have been related to dewatering of the side channel during low tides, but other areas also dewatered at low tide and catches were relatively high, e.g., Codiga cove and C-Flats.

Onshore vs. Offshore Fish Distribution Hypothesis

We tested the hypothesis that juvenile salmon were more abundant in shallow nearshore areas compared with deep mid-channel areas of the Duwamish estuary. Sampling of nearshore and mid-channel areas of the Duwamish estuary (RM 1 to 5.5) occurred on a weekly basis from early December 2004 to late February 2005. Mid-channel areas were sampled by the large purse seine, whereas nearshore areas were sampled by the PSP beach seine, which covered only 12.5% of the surface area of the purse seine. Catches were standardized by multiplying PSP seine catches by 8.

Essentially no subyearling Chinook were captured in the Duwamish estuary until the night-time beach seining effort on January 20 (first sampling after flood event), therefore tests were restricted to the period beginning in late January when Chinook salmon were present. During mid-January (week 4) to late February (week 9), 31.2 ± 5.9 Chinook fry per set were captured in 90 PSP beach seine sets (expanded counts), whereas zero subyearling Chinook salmon were captured in 41 purse seine sets in mid-channel (Fig. 18a). Densities of subyearling Chinook salmon were statistically greater in nearshore areas compared with mid-channels areas of the Duwamish estuary (df = 1, 5, 119; F = 58.341, P < 0.001). All subyearling Chinook salmon were naturally produced and small (avg. 42 mm).

Yearling and older Chinook salmon and steelhead (108 mm to 304 mm) were regularly captured each week during winter (December through February). On average, 0.7 ± 0.1 yearling and older salmon were captured in mid-channel areas compared with 1.9 ± .5 salmon in nearshore areas from early December to late February (Fig. 18b). Although catch rates tended to be greater in nearshore areas, they were not statistically different from mid-channel areas after standardizing catches by surface area sampled by the two gear types (df = 1, 12, 252; F = 1.084, P = 0.299). Both unmarked and marked salmonids were included in this analysis because too few fish were present to separately analyze marked and unmarked fish.

A number of fish species were captured in mid-channel areas of the Duwamish estuary during winter. Total fish densities were significantly greater in mid-channel areas (980 ± 227 fish per set) compared with nearshore areas (273 ± 52 fish per set) (df = 1, 12, 252; F = 56.976, P < 0.001) (Fig. 18c). Abundant species in mid-channel areas included shiner perch, herring, surf smelt, starry flounder, and shad, a non-native species that seems to be relatively new to the Duwamish. Except for shiner perch and some starry flounder, these other species were rarely captured in the nearshore beach seine.

Salmon Length and Growth

<u>Seasonal Trends</u>

Mean length of natural subyearling Chinook salmon captured in the lower river and estuary increased steadily over time from 37 mm on January 20 (week 4) to 82.8 mm on May 10 (week 20) (Fig. 19). On May 16 (week 21) mean length declined slightly to 78 mm and length remained relatively constant until a slight increase during late June. The slight decline in mean length on May 16 corresponded with an increase in juvenile Chinook salmon emigrating from RM 34.5 (Fig. 9). Mean length of Chinook salmon was similar among the three sampling zones (lower estuary, transition zone, and lower river).

Weekly change in length was used to approximate daily growth rate, based on the key assumption that fish of representative lengths were randomly migrating through the study area over time. The assumption about immigration and emigration is important because non-random movements of fish of various sizes would bias growth estimates. However, size trends over time were generally consistent at RM 34.5 and within the study area until mid-May (Figs. 19, 20), suggesting that change in size may provide a reasonable approximation of growth.

During January 20 to March 15, daily growth was relatively constant and averaged 0.27 mm (0.63% of body length) (Fig. 20). During March 22 to May 10, daily growth increased to 0.59 mm (0.93%), on average, and was relatively constant during this period. Except for April

19 (zero catch), abundance of natural Chinook salmon was moderate and relatively constant in the study area. During May 16 to late June, mean length declined then remained steady as additional Chinook emigrated from RM 34.5. The key assumption required to estimate growth was violated during this period.

Lengths of natural subyearling Chinook salmon captured in the lower river and estuary were compared with those captured at the WDFW trap at RM 34.5. Little difference in size was apparent during late January (Fig. 19), indicating some fry were rapidly moving downstream with little or no growth. From February 3 (week 6) to May 10 (week 20), mean lengths of Chinook in the lower river were consistently greater than those captured at RM 34.5. Differences in mean length peaked at 17 mm during April 4 (week 16), a period of low Chinook migration at RM 34.5 (Fig. 21). Although the residence time between RM 34.5 and the lower river is unknown (see below), the size difference between the middle Green and lower Duwamish likely reflects 1) emigration of relatively large salmon into the study area compared with those captured at RM 34.5, and/or 2) rapid growth of Chinook salmon between RM 34.5 and the estuary. Observations of larger salmon at the RM 34.5 trap compared with downstream areas during May probably represents non-random movements of larger fish through the river.

Year to Year Size Trends

Weekly size estimates of natural subyearling Chinook salmon during 2005 were compared with those during 2001-2003. Mean lengths of Chinook salmon during 2005 were consistently greater in the lower river and estuary compared with those during 2001-2003 (Fig. 22). Lengths during 2005 versus 2003 were approximately 1.5 mm greater during January and early February, increasing to 13 mm greater length during late March and early April. Length during 2005 was up to 24 mm greater than that in 2002 (early May) and up to 22 mm greater than that in 2001 (early May). Relatively warm air temperature, low river flows (see earlier section), and low abundances of juvenile Chinook salmon likely contributed to the exceptional growth of natural Chinook salmon during 2005.

Length of natural Chinook salmon at the RM 34.5 trap were also consistently greater in 2005 compared with 2001-2002 (Fig. 22). However, differences in growth between the years at the trap were typically less than that in the lower river and estuary. This finding suggests much of the additional growth in 2005 compared with previous years occurred between RM 34.5 and the lower river and estuary.

Length-Weight Relationships

The relationship between natural subyearling Chinook weight (g) and length (mm) during 2005 can be described by the following power curve (Fig. 23):

$$\text{Weight (g)} = (4.3 \times 10^{-7}) \times \text{Length}^{3.768},\ R^2 = 0.92.$$

Hatchery Chinook salmon overlapped the length-weight relationship of natural Chinook salmon, but the range in hatchery Chinook values was typically much less (5 to 95 percentile range: length 69-92 mm, weight: 3.4-9.3 g).

The length-weight relationship of natural yearling Chinook salmon less than 130 mm was compared with that of subyearling Chinook salmon. At each length interval, weight of yearling Chinook salmon was consistently less than that of subyearling Chinook salmon (Fig. 23). Growth of yearling salmon occurred primarily during 2004. The relatively low length-weight relationship of yearling salmon may reflect potentially lower growth of salmon during 2004 and/or a tendency for slower growing salmon to overwinter in the river and migrate as yearling salmon. Yearling salmon captured during this study were not likely from other watersheds, based on few non-local coded-wire-tagged salmon captured upstream of RM 0 in previous years (Nelson et al. 2004).

The length-weight relationship of natural subyearling Chinook in 2005 was compared with that in 2003. On average, Chinook salmon captured in 2005 were approximately 22% to 34% heavier at a given length compared with Chinook captured in 2003 (75-100 mm). Greater weight differential occurred among the longer salmon.

Thus, in 2005, natural Chinook salmon were longer at a given date and heavier at a given length compared with Chinook examined in prior years. Conditions in 2005 (low flow, high temperature, and low natural Chinook densities) likely contributed to relatively rapid growth of natural Chinook salmon in 2005.

<u>Size and Growth of other Salmonids</u>

Mean length of subyearling hatchery Chinook salmon was within 4 mm of the mean length of natural Chinook salmon from late April (74 mm) to mid-July (95 mm). Growth per day averaged 0.5 mm (0.7% body length) in late April and early May, remained constant during late May and early June, then increased approximately 0.63 mm per day (0.7% body length) beginning in mid-June. The period of little change in fish size (mid-May to early June) was identical to that of natural Chinook salmon.

Length of natural chum salmon averaged 42 ± 2 mm from February 18 to March 15. A consistent trend of increasing size over time was not apparent.

Approximately 2.4 million unmarked chum salmon were released from the Keta Creek Hatchery from March 21 to April 28. Natural salmon could not be distinguished from hatchery salmon beginning March 21. On March 21, chum salmon were exceptionally large, on average (46 mm), possibly reflecting natural chum salmon prior to the arrival of most hatchery salmon in the Duwamish. Mean size declined sharply from 46 mm to 38 mm on March 29, likely in response to the entry of numerous hatchery chum into the study area. From March 29 to May 16, mean length of chum salmon increased steadily from 38 mm to 46 mm, or approximately 0.17 ± 0.02 mm increase per day (0.4% body length). During May 31 to June 30, length increased more rapidly, averaging approximately 0.62 ± 0.14 mm per day (1.1% body length). Mean length of chum salmon increased from 51 mm to 68 mm during June.

We compared the estimated growth of subyearling Chinook and chum salmon based on increases in mean length (see Seasonal Trends discussion above). Daily growth of natural Chinook salmon averaged 0.77% compared with 0.70% by hatchery Chinook (weeks 19-20) and 0.40% by chum salmon from March 29 to May 10, 2005. During June 14 to June 28, daily growth of hatchery Chinook salmon averaged 0.7% compared with 1.1% by chum salmon. Thus, natural and hatchery Chinook salmon exhibited similar growth rates during early spring and their growth rates were slightly greater than chum salmon. During early summer, growth of chum salmon exceeded that of hatchery salmon (too few natural salmon present to estimate growth).

The release of numerous unmarked hatchery coho salmon fry and yearlings prevented identification of natural coho salmon. Only 17 subyearling coho salmon were captured and measured in the lower river and estuary, averaging 82 ± 8 mm. The mean date of capture was June 30. More than 350 yearling coho were captured, averaging 128 ± 18 mm. The mean date of capture was May 10. Yearling coho were present from January through May, but none were captured in June and July.

All sockeye and pink salmon were produced by naturally spawning salmon. Subyearling sockeye salmon averaged 31.8 ± 0.8 mm. Mean date of capture of measured fish was March 29 (7 fish). Pink salmon fry averaged 34.5 ± 0.6 mm and mean date of capture was March 3 (9 fish).

Naturally produced yearling and older steelhead averaged 210 ± 8 mm. Mean date of capture was April 26, but unmarked steelheads were present from December through July. Hatchery steelhead averaged 206 ± 2 mm. Mean date of capture was May 10, corresponding with the release of steelhead from the rearing ponds.

Length of cutthroat trout averaged 254 ± 13 mm. All cutthroat were age 1 or older. Mean date of capture was April 26. No bull trout were captured during 2005.

Chinook Residence Time in Middle Green River

Residence time of natural subyearling Chinook salmon in the Green River between RM 34.5 and capture in RM 1 to RM 8.5 was approximated using weekly salmon data and the following equation:

Residence time (d) = ((Length @ RM 1-8.5) – (Length @ RM 34.5)) / growth per day @ RM 1-8.5

This equation requires the assumption that sizes of fish randomly moved through each location in order to estimate growth. The relatively smooth change in size at each location prior to May 16 provides some support for this assumption. However, the estimated residence time should be viewed with caution and only as an approximation.

Residence time between RM 34.5 and RM 1-8.5 was approximately 8 days during early February, increasing to 13 days in mid-February, and to 25 ± 2 days during late February to mid-April (range: 19-32 days). There was no increasing or decreasing trend over time during late February to mid-April. Residence time estimates during late February to mid-April (25 ± 2 days) were similar to otolith-based residence time estimates of individual Chinook in the estuary in late

May, 2002 (28 ± 7 days; Ruggerone and Volk 2004). Residence time after mid-April was not estimated in 2005 because growth could not be estimated.

Prey Consumed by Chinook Salmon

Prey consumed by subyearling natural and hatchery Chinook salmon were examined from fish collected in the Transition Zone area from early February to early July. Weight of prey (all species combined) consumed by natural Chinook salmon averaged approximately 0.01 g or 1.4% of Chinook body weight from early February to March 22 (Fig. 24a, b). Consumption of prey increased and was relatively high from March 28 to May 9 (avg. .05 g), then declined to 0.027 g during May 16 to June 13 before increasing to approximately .094 g during mid- and late June. Consumption of prey standardized by Chinook body weight (i.e., percentage of body weight consumed) was moderate during late January to late March (avg. 1.4%), relatively low from late April through mid-June (avg. 0.6%), and high in late June (1.9%) when few Chinook salmon remained in the watershed and water temperature was relatively high. Importantly, these prey weight values are indices of daily consumption rates because prey pass through the stomach at a much higher rate when water temperature is high (Ruggerone 1989).

Weight of prey consumed by hatchery Chinook salmon was correlated with that of natural Chinook salmon from late April to late June ($R^2 = 0.47$) (Fig. 24a, b). Prey weight consumed by hatchery salmon (avg. 0.54 ± 0.007 g) tended to be approximately 25% greater than that of natural Chinook salmon (0.043 ± 0.006 g) during the period when both stocks were present, but this tendency was not statistically significant (df = 1, 175; F = 1.255, P = 0.264). Consumption of prey standardized by Chinook body weight was not different between hatchery (.90 ± .11%) and natural Chinook salmon (.80 ± .11%) (df = 1, 175; F = 0.100, P = 0.752).

We tested the hypothesis that consumption of prey by natural subyearling Chinook salmon is lower when large numbers of Chinook salmon are present. Median prey weight (as % of body weight) declined significantly when greater numbers of subyearling Chinook salmon (natural and hatchery) were present in the Transition Zone (n = 23, $R^2 = .28$, P = 0.009) and in all lower river and estuary sites (n = 23, $R^2 = .25$, P = 0.014) (Fig. 25). The significant relationship was largely driven by low prey weight during May 24 to June 7 when hatchery Chinook salmon were exceptionally abundant. It is noteworthy that prey weight was also relatively low during several weeks prior to the release of hatchery salmon, therefore we cannot be certain that this relationship was due to large numbers of salmon in the study area. Prey weight did not decline in response to abundance of chum salmon ($P > 0.05$) or total subyearling salmon ($P > 0.05$).

Natural and hatchery subyearling Chinook salmon consumed a variety of prey in the Transition Zone area. On average, each natural Chinook salmon contained 4.1 unique prey types (including several life stages) during January to June, whereas hatchery Chinook salmon contained 5.3 unique prey types during April to early July (Fig. 24c). The number of unique prey types was slightly higher in June compared with earlier months.

Adult, pupa, and larval midges were the most frequent prey observed in both natural and hatchery Chinook salmon throughout the study period (Table 8). Amphipods, polychaete worms, aphids, and booklice were frequently consumed. Bivalve siphons were frequently consumed during January to April, but few were consumed by natural Chinook salmon during May and June. Hatchery pellet feed was not observed in hatchery Chinook salmon probably because it was likely evacuated within 24 hrs after feeding in the hatchery. No empty stomachs were observed in Chinook from February to April, but 6% of natural and 4% of hatchery Chinook did not contain prey during May and June.

Natural and hatchery Chinook consumed similar prey types during May and June (Table 8). The variety of prey and total prey weight consumed by hatchery Chinook salmon indicated that hatchery salmon rapidly adapted to feeding on natural prey in the Transition Zone.

Natural vs. Hatchery Chinook Salmon Interactions

<u>Salmon Growth and Prey Consumption</u>

Recent studies in the Duwamish suggested that the large release of hatchery Chinook salmon may reduce growth of natural Chinook salmon (Nelson et al. 2004) or displace natural Chinook salmon from rearing areas (Ruggerone and Jeanes 2004). Examination of the potential effect of hatchery salmon on growth and rearing of natural salmon is an important issue because growth of Puget Sound Chinook salmon is important to their survival (Ruggerone and Goetz 2004).

Nelson et al. (2004) estimated growth from changes in Chinook size from week to week. This approach was also utilized here, and it is a common approach to estimating growth of Chinook salmon in estuaries (Healey 1991). However, the approach is based on the assumption that sampling of fish sizes in the estuary are representative of fish remaining in the watershed.

From May 9 to May 16, mean length of natural Chinook salmon declined from 82.8 mm to 78 mm then remained relatively constant until a slight increase during late June. The decline in mean length corresponded with an increase in juvenile Chinook salmon emigrating from RM 34.5 (Fig. 9). The decline in length also occurred before the large release of hatchery salmon from the WDFW hatchery beginning on May 21. These data confound the analysis of potential effects of hatchery salmon on the growth of natural Chinook salmon in 2005.

We tested the hypothesis that prey weight consumed by natural subyearling Chinook salmon (% body weight) declined after the release of numerous hatchery Chinook salmon from the WDFW hatchery beginning May 21. Consumption of prey was not statistically lower after May 21 compared with the period prior to the release of hatchery salmon (df = 1, 202, F = 1.478, P = 0.225), although there was a tendency for lower prey consumption after the release of hatchery Chinook salmon.

The decline in prey weight consumed by natural subyearling Chinook salmon began in mid-April, corresponding with the arrival of subyearling hatchery salmon that apparently escaped through Howard Hanson Dam prior to re-fill (Fig. 24b). Consumption of prey was statistically lower after April 18 (0.80 ± .11%) compared with the period prior to the release of all hatchery salmon (1.46 ± .09%) (df = 1, 202, F = 21.58, P < 0.001). The decline in prey consumption began prior the second migration of natural Chinook from RM 34.5 (Fig. 9), indicating the influx of fish from the middle Green River did not influence the reduction in prey. The decline in prey consumption corresponded with the arrival of fish from the lower Green River salmon rather than with the increase from the middle Green River. As described above, consumption of prey was not correlated with the abundance of chum fry, which were exceptionally abundant from late March through early May.

In conclusion, data collected in 2005 were insufficient to test the hypothesis that the release of hatchery Chinook salmon affected the growth of natural subyearling Chinook salmon. Numerous hatchery salmon may have contributed to the low consumption of prey when hatchery fish were abundant, but prey consumption was also low during several weeks prior to the major release of Chinook salmon. In 2005, prey availability in appeared to be relatively high in response to warm temperature and low flows (based on rapid growth) and abundances of natural Chinook salmon were low, therefore competitive interactions may have been less in than in other years.

CONCLUSIONS

- Our findings in 2005 were consistent with previous studies that indicated densities of subyearling Chinook salmon were higher in the Transition Zone (RM 6.5 to at least RM 4.6) compared with adjacent reaches such as the lower estuary. However, lower river habitats also supported relatively large catches of fingerling Chinook salmon during late March through mid-May. The lower river supported the highest catches of all three zone from late May through early July. This shift in habitat utilization may reflect different behavioral and physiological responses of Chinook fry versus Chinook fingerlings to salinity. The shift might also reflect the lack of low velocity habitats in the lower river to support Chinook fry during the early migration period, but in 2005 flows and velocities were exceptionally low except for late January.

- Data collected in 2005 and in previous years suggest that priority should be given to restoration projects in the Transition Zone and lower Duwamish River, if possible. While restoration projects in the lower estuary will provide benefits for juvenile salmon, available data suggest that juvenile Chinook salmon migrate through this reach relatively quickly and spend relatively little time in off-channel habitats within this reach.

- Densities of subyearling salmon were significantly greater in off-channel habitats compared with mainstem habitats in the lower river, but significantly less in off-channel habitats in lower estuary. This pattern may reflect behavioral differences of Chinook inhabiting freshwater vs. marine habitats. This finding suggests that restoration projects in the lower river should focus on construction of off-channel habitats, whereas projects in the lower estuary might focus on projects along the mainstem. However, only two site comparisons were made, one in the lower river and one in the lower estuary.

- Catches of Chinook salmon were low in relatively high quality habitat in the lower estuary (Kellogg Island) compared with areas in the Transition Zone and lower river. This observation suggests that salmon respond to this reach as part of the Puget Sound nearshore rather than an estuary where salmon may aggregate, feed, and grow. This reach is characterized by a deep dredged channel of marine water bordered by a narrow band of intertidal habitat. Recapture of coded-wire-tagged salmon indicates Chinook salmon migrate rapidly along nearshore areas of Puget Sound rather than hold and rear in specific habitats (Nelson et al. 2004).

- Habitats having gentle intertidal gradients and lower velocities tended to support higher Chinook densities. The highest catches occurred in a large intertidal mudflat area that was protected from high velocities. Bank armoring and restored upper tidal and upland areas were not associated with higher catches. These findings suggest that restoration of salmon habitat should maximize additional intertidal habitat while providing fringe marsh and upland habitat to support prey production.

- Surface area of restored habitats should be maximized in order to support large numbers of natural and hatchery salmon. Ideal habitats appear to be large areas having gentle intertidal mudflat slopes that are protected from currents while also providing refuge in a channel during low tides. Most existing restoration sites are dewatered during much of the tide cycle (dewatered near +6 ft MLLW), thereby limiting access of fish to the sites and forcing fish back into the mainstem river.

- Natural subyearling Chinook salmon were considerably more abundant in nearshore compared with mid-channel habitats of the Duwamish estuary during late January and February. This finding provides evidence that restoration projects should focus in nearshore areas.

- Catches of natural Chinook salmon were relatively low in 2005 in spite of relatively high numbers of parent spawners in 2004. Some key spawning areas appeared to be crowded. Additional research is needed to evaluate the capacity of the Green River to support Chinook spawners.

- Chinook size and growth rate were greater in 2005 compared with previous years apparently because water temperature was high, water flows were low, and natural Chinook abundance was low.

- Consumption of prey by Chinook salmon was consistently low during three weeks when hatchery salmon were highly abundant in the lower river and estuary, but low feeding also occurred prior to the arrival of hatchery Chinook salmon. This pattern confounded the analysis to evaluate whether hatchery salmon influenced feeding rates of natural Chinook salmon in 2005. Hatchery Chinook salmon dominated the catches during the period when most natural fingerling Chinook migrate through the lower river and estuary (i.e., 89% of total Chinook catch during mid-May through early July).

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Table 1. Characteristics of sites sampled by river beach seine during 2005.

Location	RM	River Bank	Substrate	Eddy Potential?	Slope (tidal zone)	Bank Armor	Bank Type	Primary Bank Vegetation	Secondary Bank Vegetation	Rehabilitated Site?
Codiga Inside	8.5	right	boulder/mud /gravel	yes	16°	rip-rap	un-natural	landscaped	mixed	yes
Codiga Outside	8.5	right	sand/mud	yes	9°	none	natural	weeds	Deciduous	no
Tukwila Br	7.0	left	mud	no	13.5°	rip-rap	un-natural	blackberry		no
Spawner Beach	6.6	left	gravel	no	6°	rip-rap	un-natural	blackberry	reed canary grass	no
Trimaran	6.5	right	mud	yes	4°	rip-rap	un-natural	blackberry	reed canary grass	no
Sabey	6.3	left	mud	no	10°	none	natural	marsh, grasses	mature deciduous	no
USFWS	5.6	left	mud	yes	3°	none	mixed	blackberry	immature deciduous	no
Turning Basin	5.5	left	mud	yes	4°	none	natural	marsh	immature deciduous	yes
Hamm Cr	5.2	left	sand/mud	no	5°	none	natural	grasses	restored	yes
C-Flat	4.7	right	mud	yes	1.5°	rip-rap	un-natural	blackberry	none	no
SeaKing	4.6	left	mud/cobble	yes	10°	rip-rap	un-natural	blackberry	none	no
Pit Bull	3.5	left	sand/mud	yes	5°	rip-rap; none	mixed	blackberry	grass	no
Gravel Beach	2.3	right	gravel/sand	yes	9°	rip-rap	un-natural	blackberry	none	no
Kellogg East	1.0	left	mud	yes	5°	none	natural	blackberry	mature deciduous	no
Kellogg West	1.0	left	mud	yes	2°-10°	none	natural	blackberry	mature deciduous	no

Table 2. Number of beach seine sets made at each sampling area in the Green/Duwamish River. Routine sampling with the river seine occurred from February 3 to July 12, 2005. Seining with the Puget Sound protocol net (PSP) occurred during winter (SAIC et al. 2004) and it was used here primarily to examine early catch rates of juvenile Chinook salmon. Additionally, 88 sets with a purse seine in mid-channel waters were made from December 4 to February 25 in order to examine relative densities of salmon in the mid-channel.

Location	River Mile	Period	Seine	No. sets/ wk	Total sets
Codiga Inside	8.5	Feb 3 to Jul 12	River	1.5	35
Codiga Outside	8.5	Feb 3 to Jul 12	River	3.0	71
Tukwila Bridge	7.0	Feb 3 to Jul 12	River	2.3	54
Spawner Beach	6.6	Feb 3 to Jul 12	River	1.0	25
Trimaran	6.5	Feb 3 to Jul 12	River	3.1	78
Sabey	6.3	Feb 3 to Jul 12	River	2.0	47
Turning Basin	5.6	Mar 8 to Jul 7	PSP	1.0	18
Turning Basin	5.5	Feb 3 to Jul 12	River	3.1	86
Hamm Creek	5.2	Feb 3 to Jul 12	River	3.0	78
C-Flat	4.7	Feb 10 to Jul 12	River	2.9	69
SeaKing	4.6	Feb 3 to Jul 12	River	2.9	70
Pit Bull	3.5	Feb 3 to Jul 12	River	2.3	60
Gravel Beach	2.3	Feb 3 to Jul 12	River	3.0	73
Kellogg East	1.0	Feb 3 to Jul 12	River	3.0	78
Kellogg West	1.0	Feb 3 to Jul 12	River	3.0	72
			Totals	2.6	914
Trimaran	6.5	Dec. 4 to Mar 3	PSP	2.9	40
Turning Basin	5.5	Dec. 4 to Mar 3	PSP	2.9	41
Hamm Cr area	5.2	Dec. 4 to Mar 3	PSP	2.6	37
Pit Bull	3.5	Dec. 4 to Mar 3	PSP	2.9	40
Kellogg East	1.0	Dec. 4 to Mar 3	PSP	3.0	42
			Totals	2.9	200

Table 3. WDFW (Soos Cr) hatchery releases, 2005. Mike Wilson, WDFW, 10/7/05; updated by T. Kane, USFWS, 2/1/06, pers. comm.

Species	Age	Location	Release Date	Number released: Ad+CWT	CWT only	AD only	% no clip	Fish/lb	wt (g)	Length (mm)
Chinook	subyearling	Soos Cr	21-May			557,000		78	5.8	
			21-May	71,717				78	5.8	83
			21-May		72,122			78	5.8	83
			25-May			224,000	3.92	83	5.5	82
			25-May			224,000	2.53	73	6.2	85
			25-May			224,000	3.73	81	5.6	82
			27-May			553,000	3.75	63	7.2	88
			27-May	41,734			3.75	63	7.2	89
			27-May		41,067		3.75	63	7.2	89
			31-May			224,000	2.97	83	5.5	82
			31-May			224,000	6.06	87	5.2	81
			31-May			224,000	6.48	89	5.1	81
			2-Jun			559,000	2.97	66	6.9	87
			2-Jun	91,739			2.97	66	6.9	86
			2-Jun		91,900		2.97	66	6.9	86
			Totals	205,190	205,089	3,013,000	4.13		6.2	71
					Grand total:	3,423,279	141,381			
Chinook	yearling	Icy Cr ponds	May 3-May 13	78,585	0	202,078	3.11	10	45.4	163
Coho	subyearling	Duwamish R	3-Mar				71,700			
	subyearling	Soos Cr	11-Apr				1,000			
	subyearling	Covington C	17-Feb				125,000			
	yearling	Soos Cr	20-Apr	45,500	45,500	694,100		15	30.2	137
					Grand total:	982,800	197,700			
Winter Steelhead	yearling	Soos Cr	1-May	0	0	34,500		5.0	90.7	209
			1-May			46,000	Ad+LV	6.5	69.8	186
		Palmer	May 1-May 10	0	0	190,918		5.2	87.2	
		Icy Cr		0	0	0				
		Flaming Geyser		0	0	0				
			Totals	0	0	271,418	6,595			198
Summer Steelhead	yearling	Soos Cr				34,500		5.0		208
		Palmer	May 1-May 10			89,843		5.2	87.2	209
		Icy Cr	May 3-May 13			33,120		5.4	84.0	
						157,463	3,826			

Table 4. Muckleshoot Indian Tribe (MIT) hatchery releases, 2005. T. Kane, USFWS, 2/1/06, pers. comm.

Species	Age	Date	Location	Number released: Ad+CWT	CWT only	AD only	No mark	% no clip
Chinook	subyearling	March 10-25	Above H. Hanson Dam			541,311	28,897	5.1%
Coho	subyearling	March 22-25	Above H. Hanson Dam				546,450	100%
Coho	yearling	May 4-6	Crisp Cr	45,419	1,169	2,428	190,534	80.0%
			Totals:	45,419	1,169	2,428	736,984	
						Grand total:	786,000	
Chum	subyearling	March 21-April 28	Crisp Cr				2,394,000	

Table 5. Estimate of good, partial, and unrecognizable (bad) fin clips on untagged subyearling Chinook salmon at the WDFW hatchery on May 9, 2005.

Pond	No. Fish	Length (mm)	Fish/lb	Clip Method	CWT?	Adipose clip rates (number sampled) Good	Partial	Bad	Total	Adipose clip rates (%) Good	Partial	Bad
		(May 6)	(May 6)									
10	549,000	72.7	127	Hand	no	1,454	47	46	1,547	93.99%	3.04%	2.97%
11	549,000	72.3	129	Hand	no	1,417	46	57	1,520	93.22%	3.03%	3.75%
12	224,000	75.2	115	Hand	no	712	20	45	777	91.63%	2.57%	5.79%
13	224,000	74.7	117	Hand	no	732	28	31	791	92.54%	3.54%	3.92%
14	224,000	72.7	127	Hand	no	688	25	46	759	90.65%	3.29%	6.06%
15	224,000	69.1	148	Hand	no	484	21	35	540	89.63%	3.89%	6.48%
16	224,000	77.0	107	Hand	no	489	12	13	514	95.14%	2.33%	2.53%
17	224,000	75.2	115	Hand	no	482	9	19	510	94.51%	1.76%	3.73%
					Sum:	6,458	208	292	6,958	92.81%	2.99%	4.20%
						Mean weighted by fish in ponds:				92.91%	2.96%	$\boxed{4.13\%}$

Definitions:

Good clip: easily recognizable as an adipose fin clip.
Partial clip: 50% or more of adipose fin present; identifiable as hatchery fish after close examination.
Bad clip: Likely would have been identified as natural Chinook in Duwamish R.

Table 6. Summary of ANOVA statistics assessing differences in natural subyearling Chinook salmon by location, time period, and river zone.

Test	Dependent Variable	Independent Variables	Degrees Freedom	F-Value	P-Value
1	Subyearling Chinook	Location	13, 816	3.738	<0.001
		Period	2, 816	7.420	<0.001
		Location x Period	26, 816	1.953	0.003
2	Subyearling Chinook	Zone	2, 849	10.236	<0.001
		Period	2, 849	6.651	0.001
		Zone x Period	4, 849	6.348	<0.001
3a	Subyearling Chinook	Zone (May 23-July 12)	2, 281	8.512	<0.001
3b	Subyearling Chinook	Zone (Mar 26-May 16)	2, 284	6.532	0.002
3c	Subyearling Chinook	Zone (Jan 23-Mar 21)	2, 284	8.305	<0.001

Table 7. Geometric mean catch of natural subyearling Chinook salmon at each of 14 sampling locations and a matrix of statistical tests (P-values) indicating whether catch was significantly different between locations in the matrix (columns vs. rows). Paired locations having a matrix P-value < 0.05 had statistically different abundances of Chinook salmon at $\alpha = 0.05$. Tests based on multiple range tests of a two factor ANOVA (location & week) where overall df = 13, 523. Values based on weekly sampling of each site by river seine from February 3 to July 12, 2005. Column are organized by river mile, whereas rows are organized by decreasing geometric mean catch. P-values above the highlighted cells indicate catch at locations in row were less than catch at corresponding location in column. P-values above the highlighted cells indicate catch at locations in row were greater, on average, than catch at corresponding location in column. P-values up to 0.20 are shown (i.e., 20% chance of incorrectly rejecting null hypothesis of no difference between sites). Blank cells indicate no statistical difference (P > 0.20).

Location	Geometric mean	Codiga Inside (8.5)	Codiga Outside (8.5)	Tukwila Br (7.0)	Spawn Beach (6.6)	Trimaran (6.5)	Sabey (6.3)	Turn Basin (5.5)	Hamm Cr (5.2)	C-Flat (4.7)	SeaKing (4.6)	Pit Bull (3.5)	Gravel Beach (2.3)	Kellogg East (1.0)	Kellogg West (1.0)
C-Flat (4.8)	2.004	0.037	0.001	0.001	0.004	<0.001	<0.001	0.012	0.009		0.006	<0.001	<0.001	<0.001	<0.001
Turn Basin (5.5)	1.102			0.052			0.056			0.012		0.160	0.016	0.050	0.002
Codiga In (8.5)	1.073			0.120			0.125			0.037			0.063	0.133	0.013
Hamm Cr (5.1)	1.067			0.067			0.072			0.010		0.198	0.022	0.067	0.002
SeaKing (4.7)	1.010			0.101			0.106			0.006			0.039	0.104	0.005
Codiga Out (8.5)	0.811									0.001			0.177		0.034
Trimaran (6.5)	0.791									0.001			0.202		0.040
Pit Bull (3.5)	0.697							0.160	0.200	0.001					0.121
Spawn Beach (6.8)	0.692									0.004					
Kellogg E (1.0)	0.592	0.130						0.049	0.067	<0.001	0.104				
Tukwila Br (7.5)	0.553	0.120						0.052	0.068	<0.001	0.101				
Sabey (6.3)	0.543	0.130						0.056	0.072	<0.001	0.106				
Gravel B. (2.0)	0.495	0.060	0.180			0.201		0.016	0.022	<0.001	0.039				
Kellogg W (1.0)	0.338	0.010	0.030			0.040		0.002	0.002	<0.001	0.005	0.121		0.220	

Table 8. Frequency of occurrence of prey in the diet of subyearling natural and hatchery Chinook salmon captured in the Transition Zone area, February to June, 2005. Values are the proportion of Chinook salmon containing each prey type.

		Natural Chinook			Hatchery Chinook
Prey type/ life stage	Common name	Feb & March	April	May & June	May & June
	Number of Chinook examined:	90	30	86	89
Diptera (Nematocera) Pupa	midge	0.53	0.27	0.36	0.40
Diptera (Nematocera) Larva	midge	0.49	0.07	0.10	0.19
Diptera (Nematocera) Adult	midge	0.42	0.43	0.80	0.83
Amphipoda Adult	Corophium sp.	0.33	0.37	0.50	0.49
Pelecypoda	bivalve siphon	0.33	0.50	0.02	0.00
Polychaete Adult	nereid worm	0.28	0.37	0.20	0.11
Diptera (Brachycera) Larva	dance fly	0.18	0.10	0.05	0.07
Collembola Adult	springtail	0.18	0.03	0.01	0.07
Unidentified		0.17	0.37	0.15	0.19
Homoptera Adult	aphid	0.10	0.10	0.37	0.48
Psocoptera Adult	booklice	0.10	0.07	0.29	0.30
Cladocera Adult	Daphnia sp.	0.10	0.63	0.01	0.04
Diptera (Brachycera) Adult	emergent	0.09	0.03	0.26	0.36
Cumacea Adult	cumacean	0.08	0.13	0.03	0.01
Oligochaete Adult	annelid worm	0.04	0.07	0.00	0.00
Acari Adult	mite	0.02	0.00	0.02	0.01
Plant Matter		0.01	0.10	0.10	0.18
Hymenoptera Larva	ant, bee, wasp	0.01	0.00	0.00	0.00
Orthoptera Nymph	grasshopper	0.01	0.00	0.00	0.00
Plectoptera Nymph	stonefly	0.01	0.00	0.00	0.00
Hymenoptera Adult	ant	0.00	0.00	0.33	0.36
Coleoptera Adult	rove beetle	0.00	0.07	0.16	0.17
Araneae Adult	spider	0.00	0.03	0.10	0.13
empty stomach		0.00	0.00	0.06	0.04
Mysidacea Adult	Neomysis sp.	0.00	0.13	0.05	0.00
Hemiptera Adult	seed bug	0.00	0.00	0.01	0.03
Hemiptera Nymph	just hatched	0.00	0.00	0.01	0.02
Tanaidacea Adult	tanaid	0.00	0.00	0.01	0.02
Tricoptera Adult	caddis fly	0.00	0.03	0.01	0.02
Diplopoda Adult	millipede	0.00	0.00	0.01	0.00
Insecta Adult	abdomen	0.00	0.00	0.01	0.00
Lepidoptera Adult	moth	0.00	0.03	0.01	0.00
Diptera (Brachycera) Pupa	parts	0.00	0.03	0.00	0.03
Isopoda Adult	pillbug	0.00	0.00	0.00	0.02
Chilopoda Adult	centipede	0.00	0.00	0.00	0.00
Ephemeroptera Adult	mayfly	0.00	0.03	0.00	0.00
Gasterosteiformes Larva	stickleback; 20mm	0.00	0.00	0.00	0.00
Teleostei Larva	larval fish	0.00	0.07	0.00	0.00

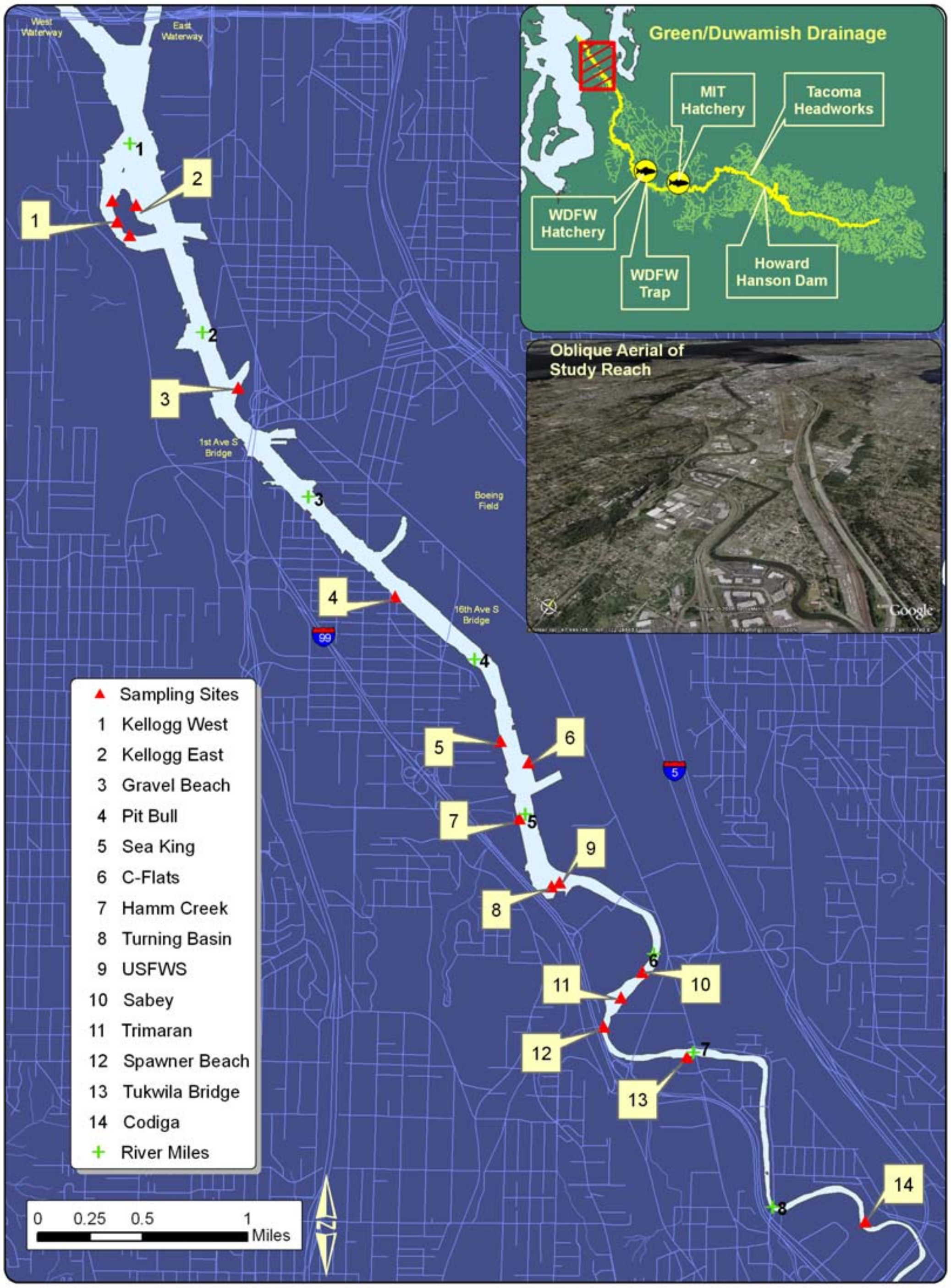


Fig. 1. Location of sampling sites in the lower Duwamish River and estuary, 2005.

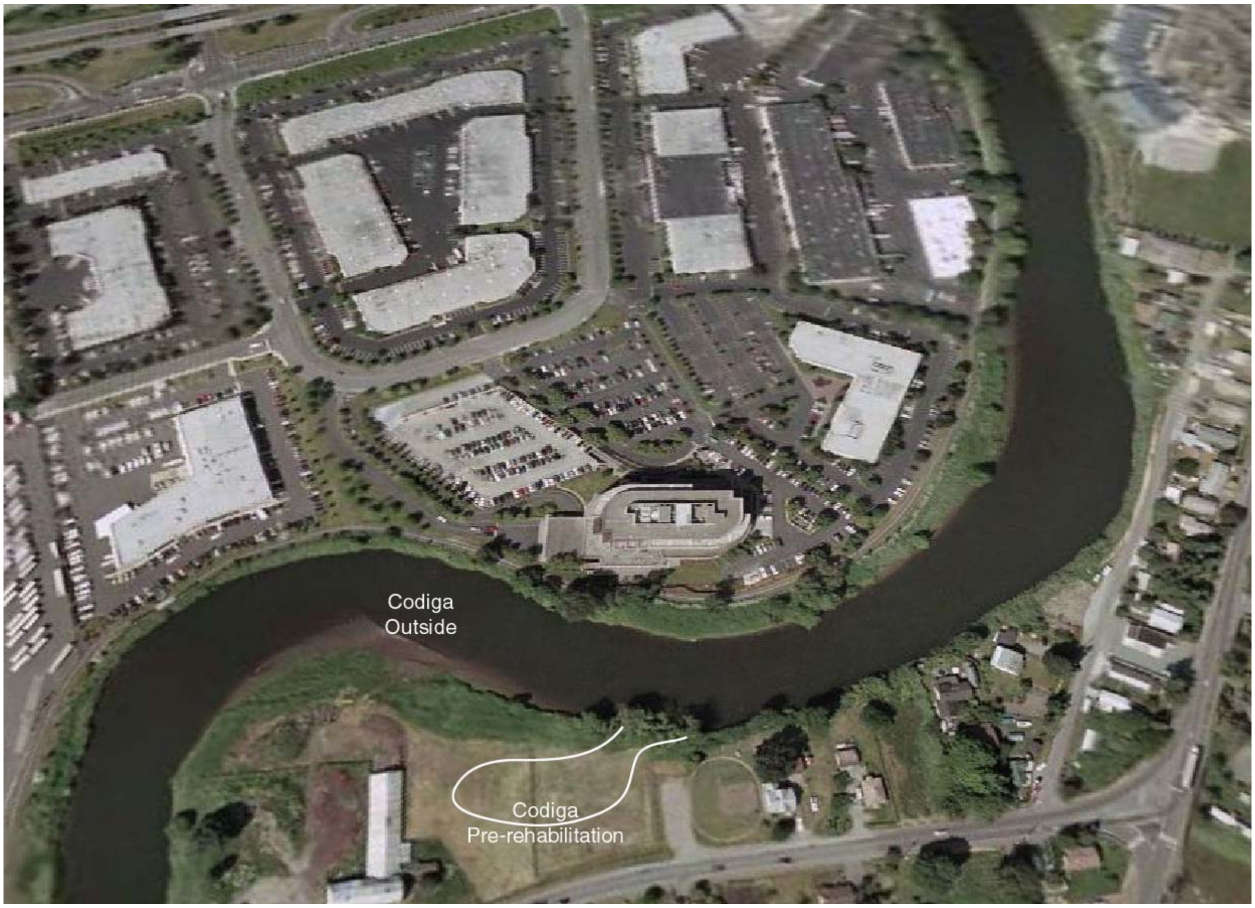
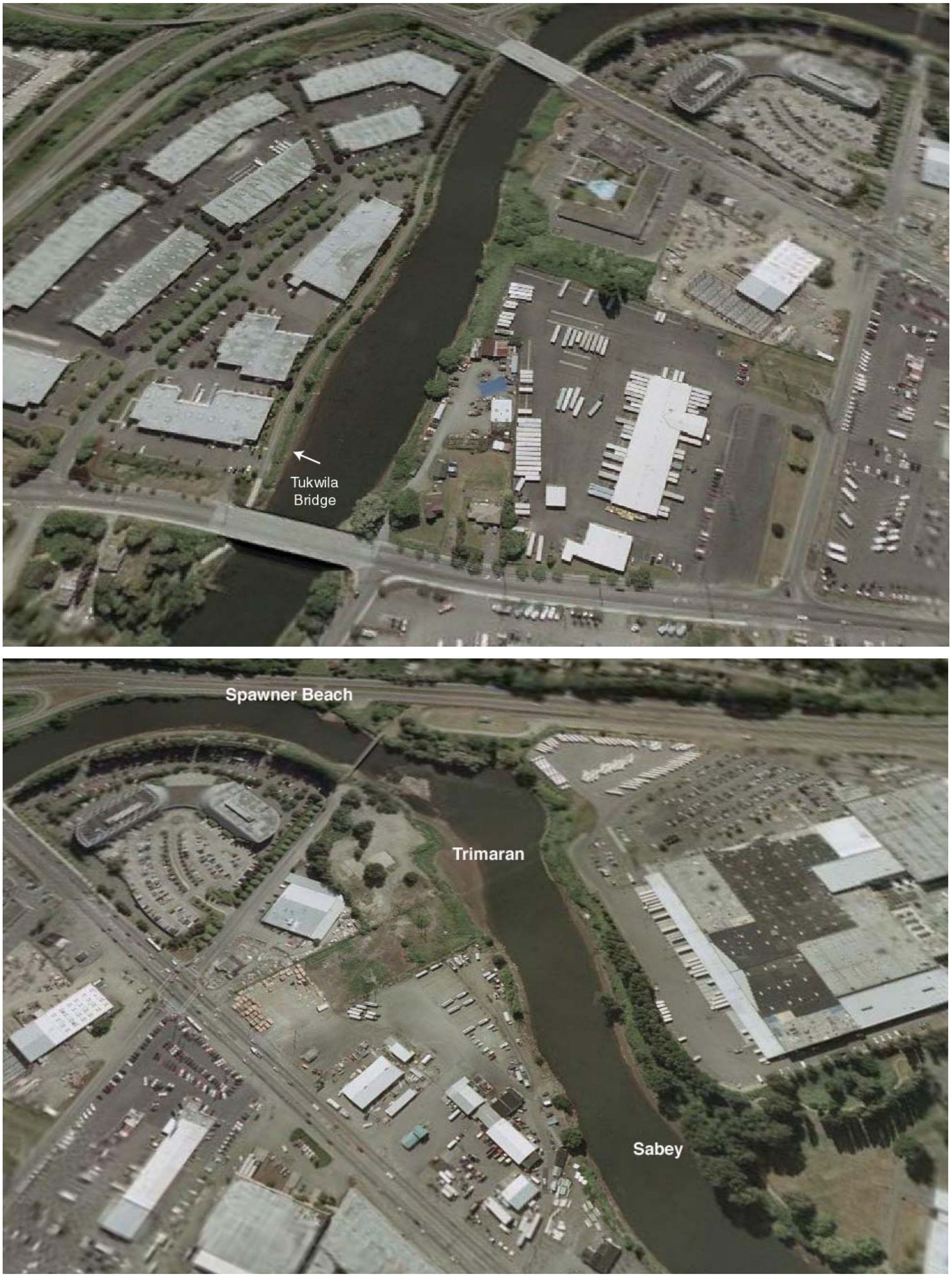


Fig. 2. Photographs of each sampling area. Lower photo is Codiga restoration site.



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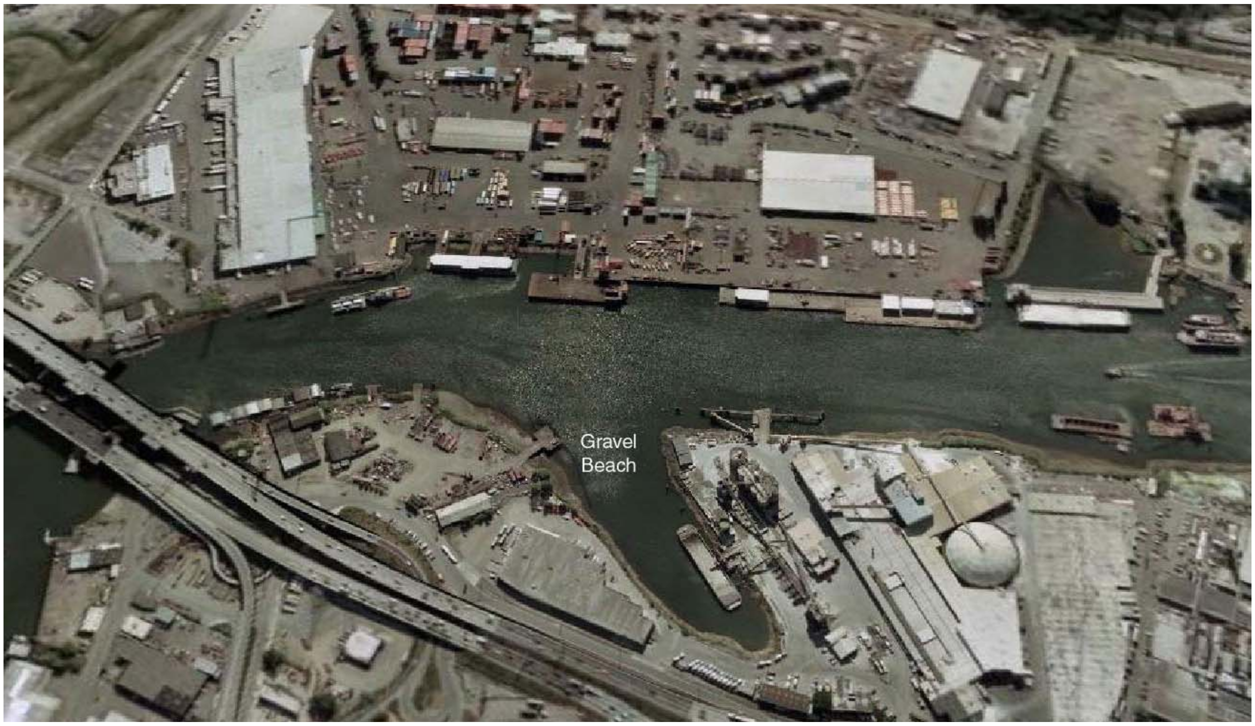


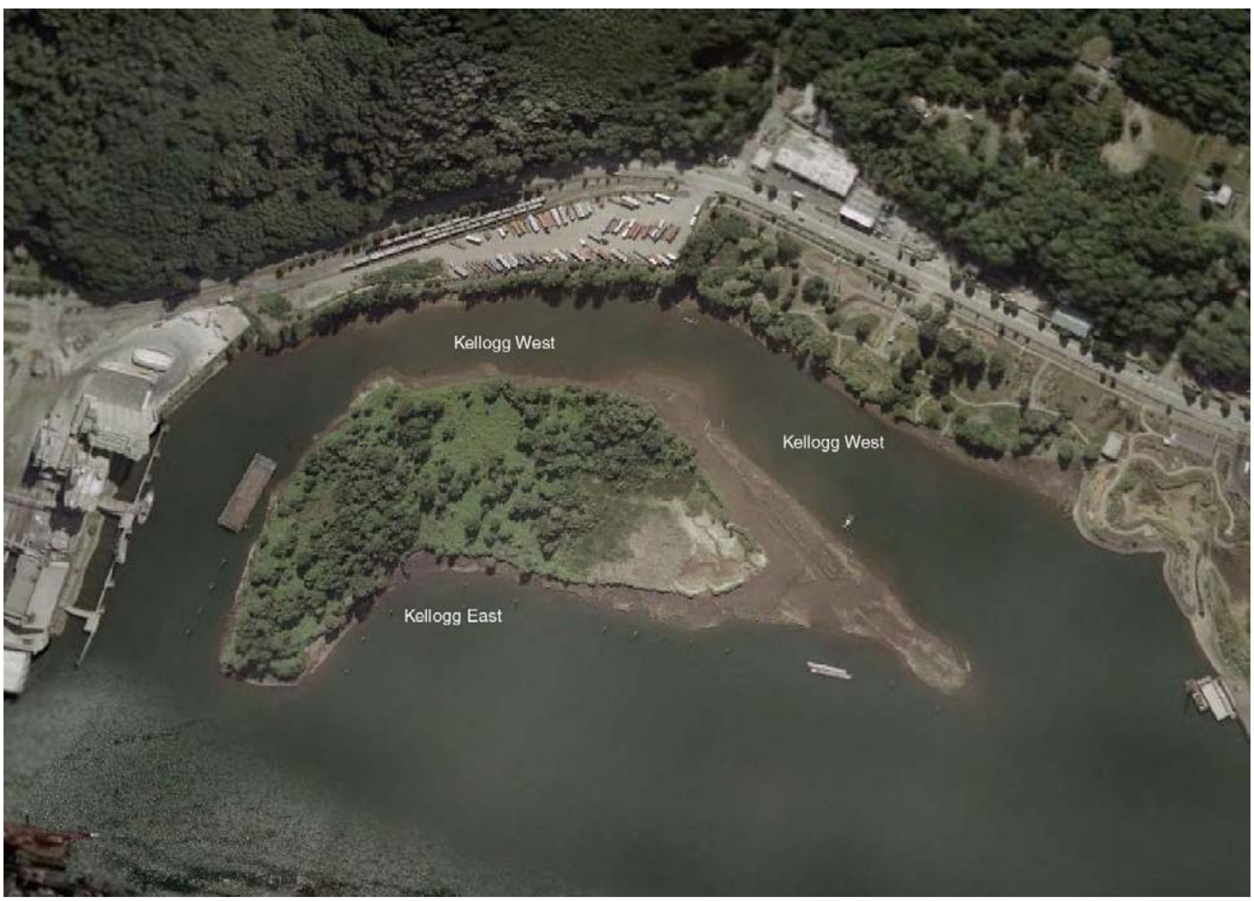


Fig. 2. Continued.

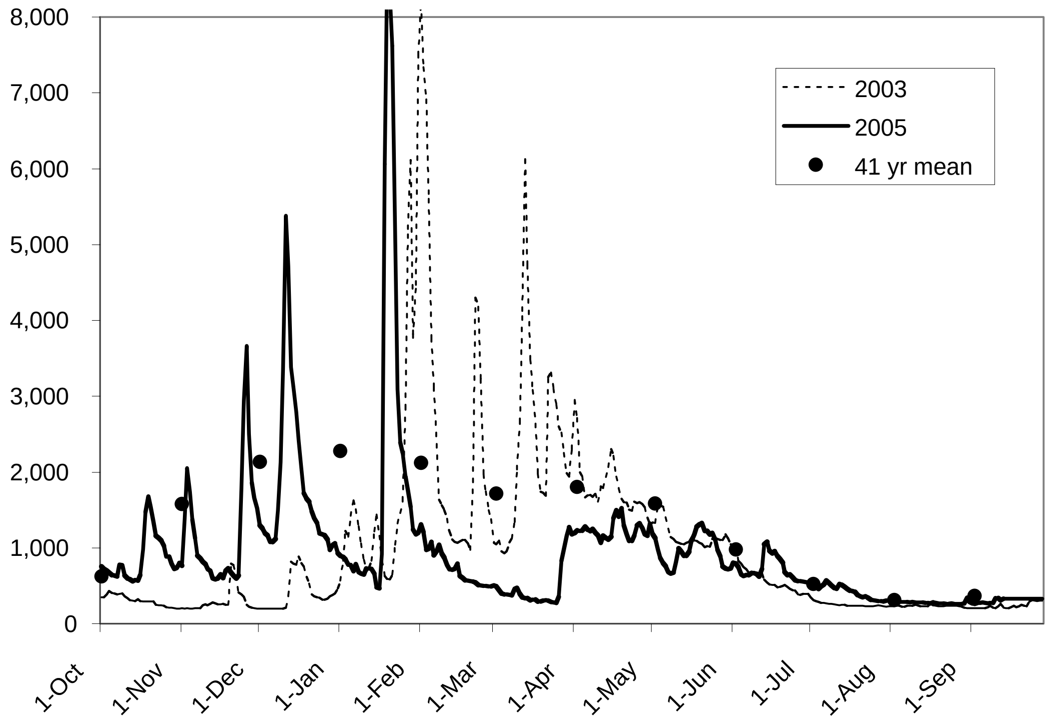


Fig. 3. Daily flow of Green River (Auburn gage 12113000) during 2003 and 2005 compared with the historical monthly mean discharge. Water year begins October 1.

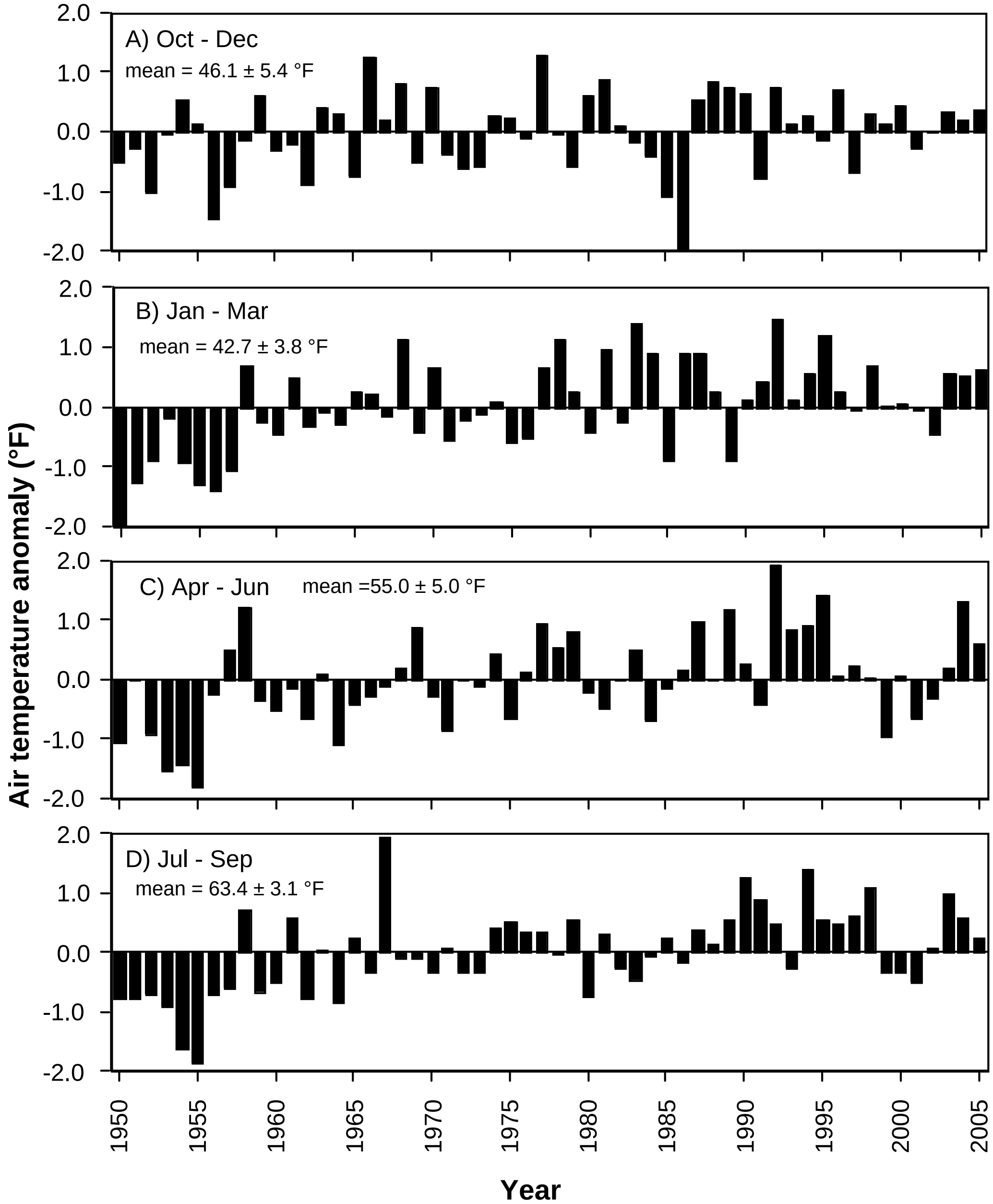


Fig. 4. Air temperature anomaly at SeaTac Airport, 1950-2005. Values are standard deviations above and below the long-term mean for each three month period during the water year (October to September).

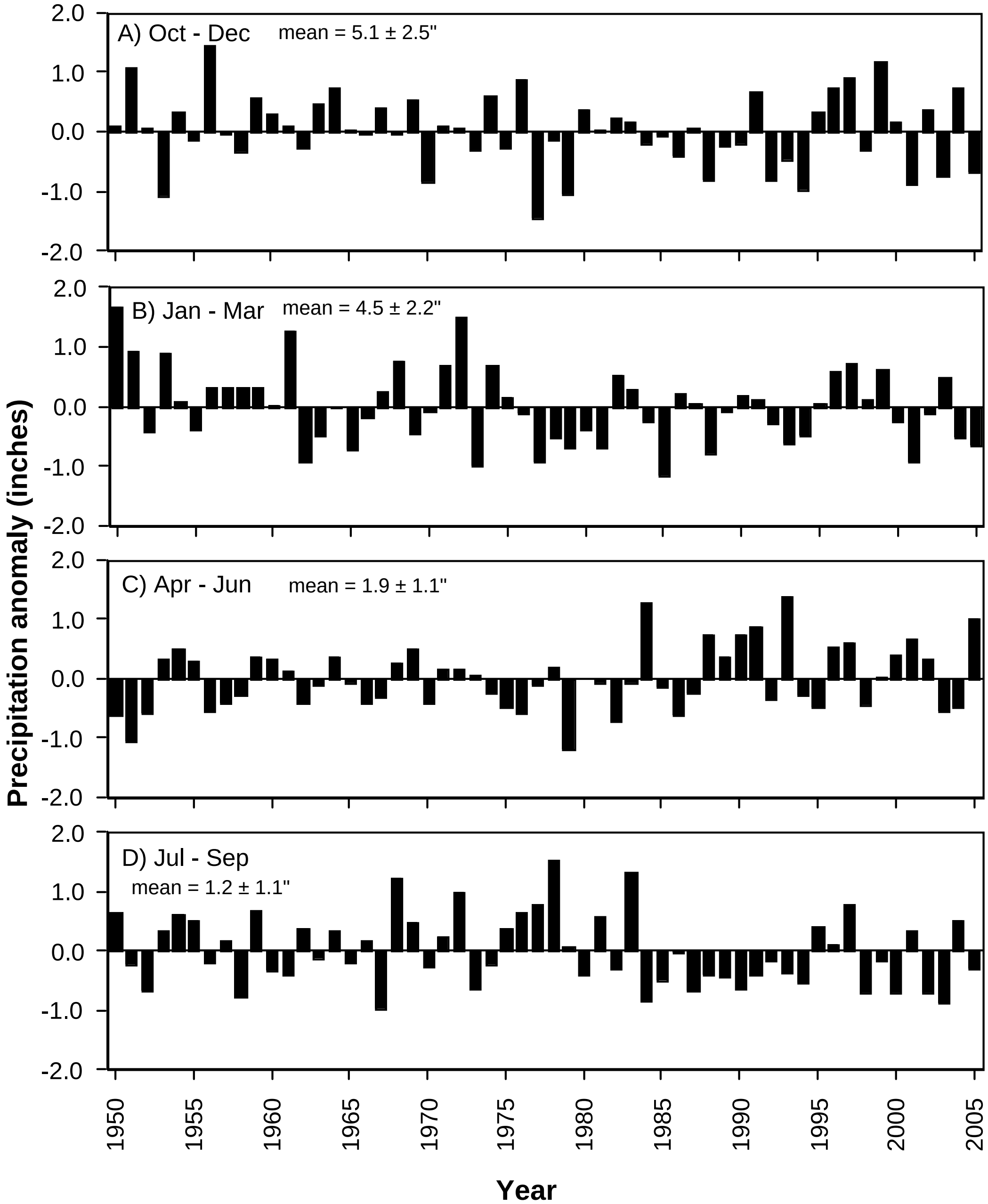


Fig. 5. Precipitation anomaly at SeaTac Airport, 1950-2005. Values are standard deviations above and below the long-term mean for each three month period during the water year (October to September).

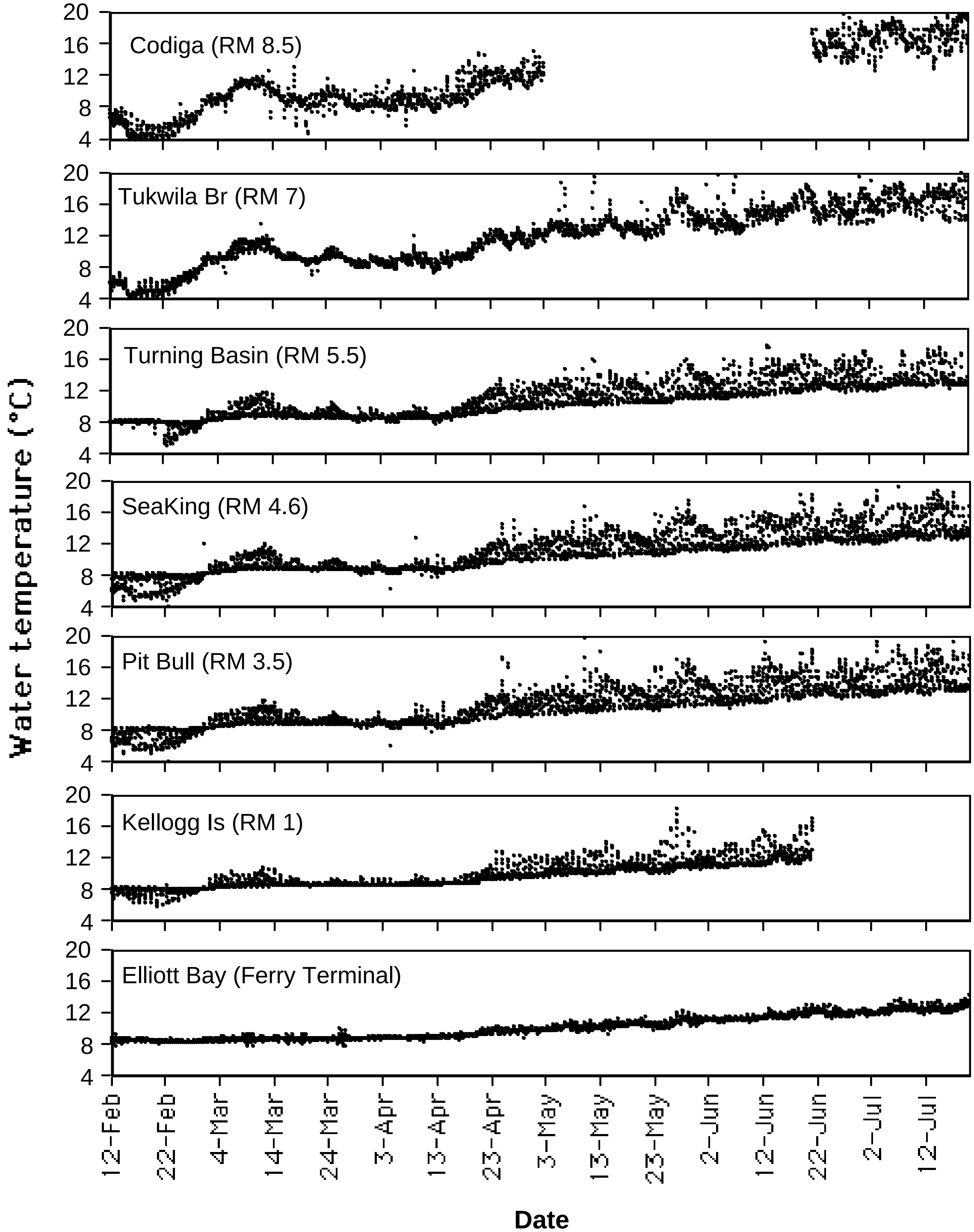


Fig. 6. Water temperature at selected sampling sites ranging from Kellogg Island (RM 1) to Codiga (RM 8.5), February 12 to July 2, 2005. Thermographs set near substrate within nearshore area sampled by the river seine. Temperature recorded every hour.

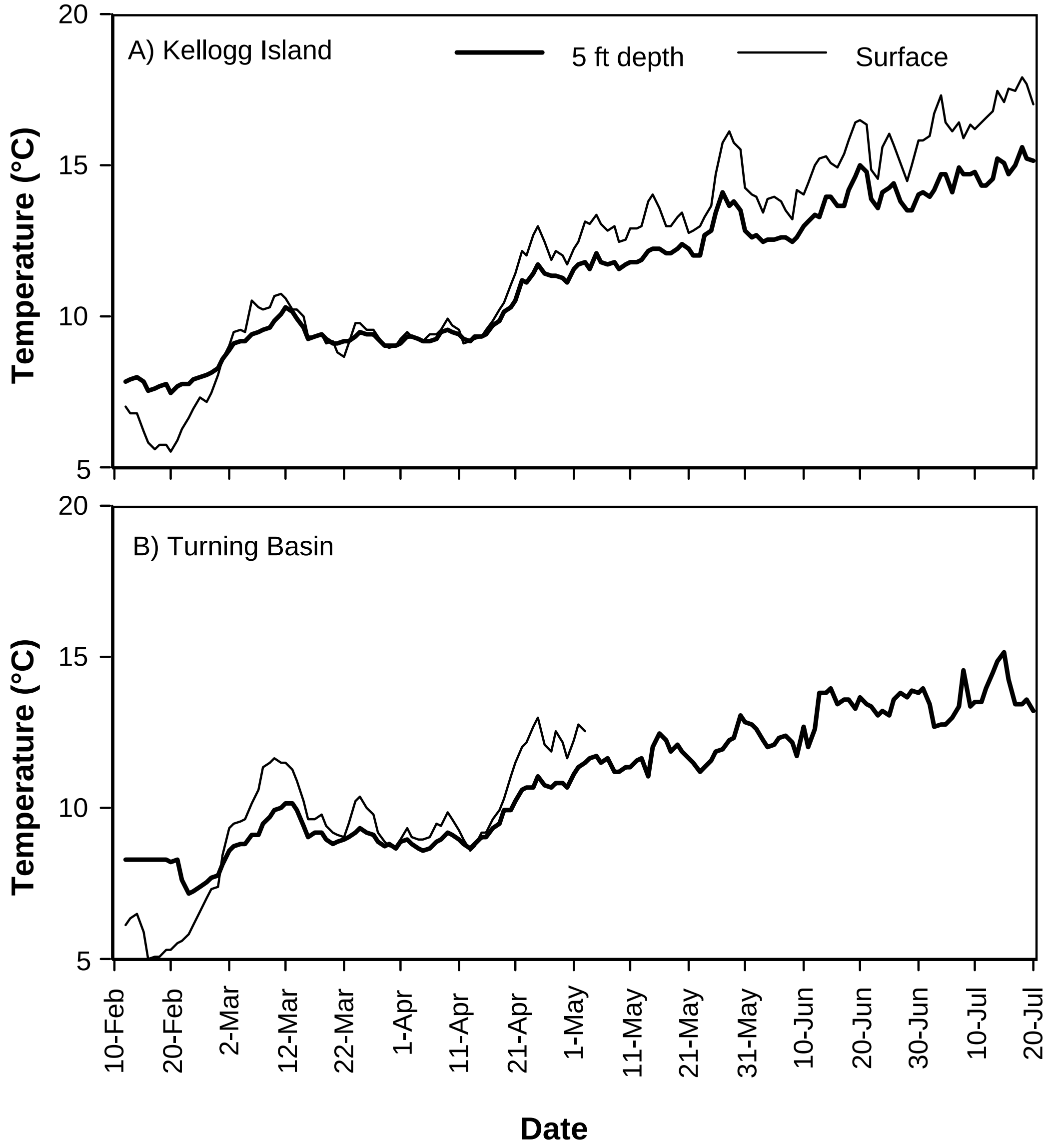


Fig. 7. Comparison of daily mean water temperature at the surface and 5 ft depths at Kellogg Island and the Turning Basin. Surface thermograph at the Turning Basin was lost in early May.

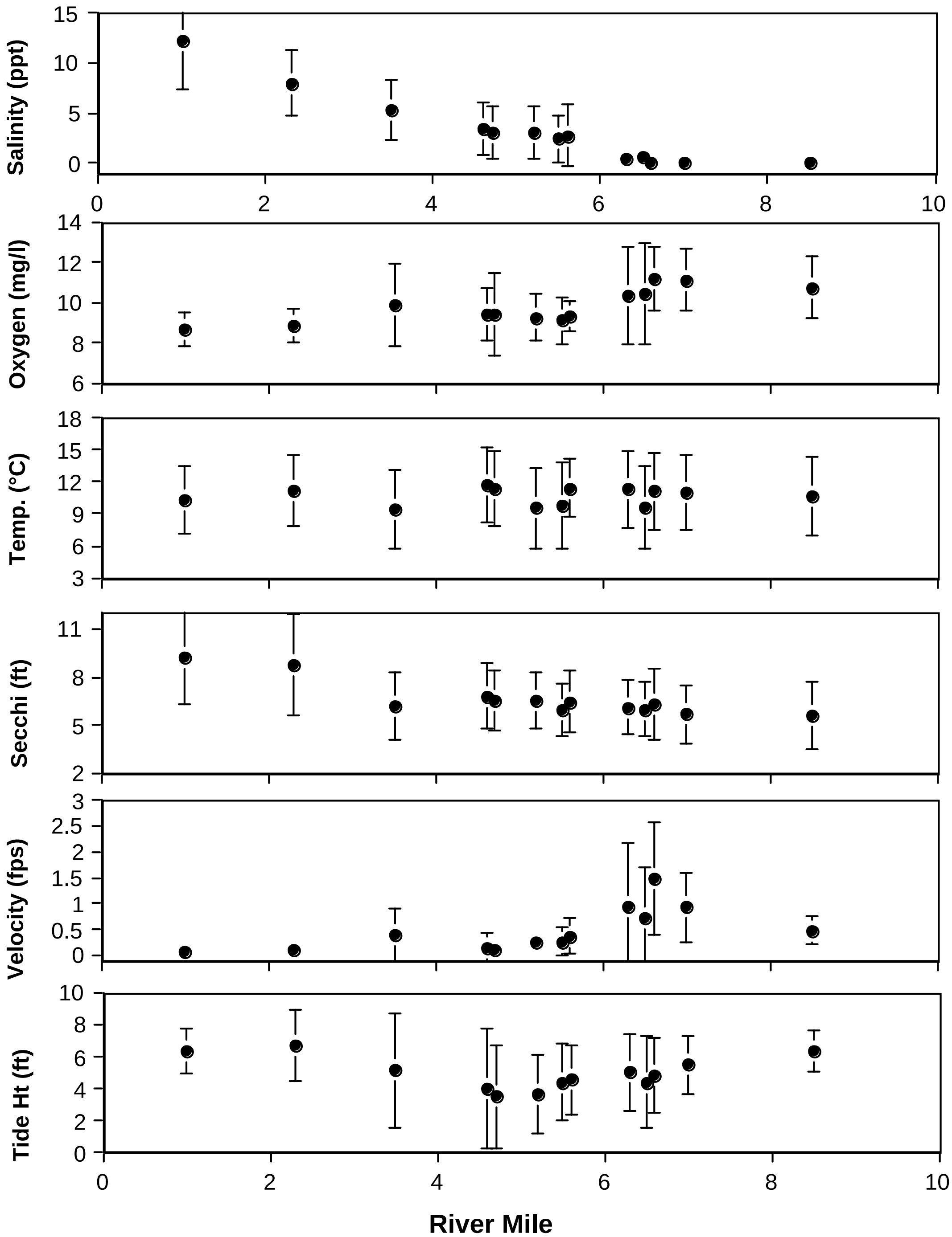


Fig. 8. Water quality, water velocity, and tidal height of sampling locations in the lower Duwamish river and estuary from February 3 to July 12. Values are mean ± 1 SD. Salinity and oxygen values were taken from 2.5 ft depth.

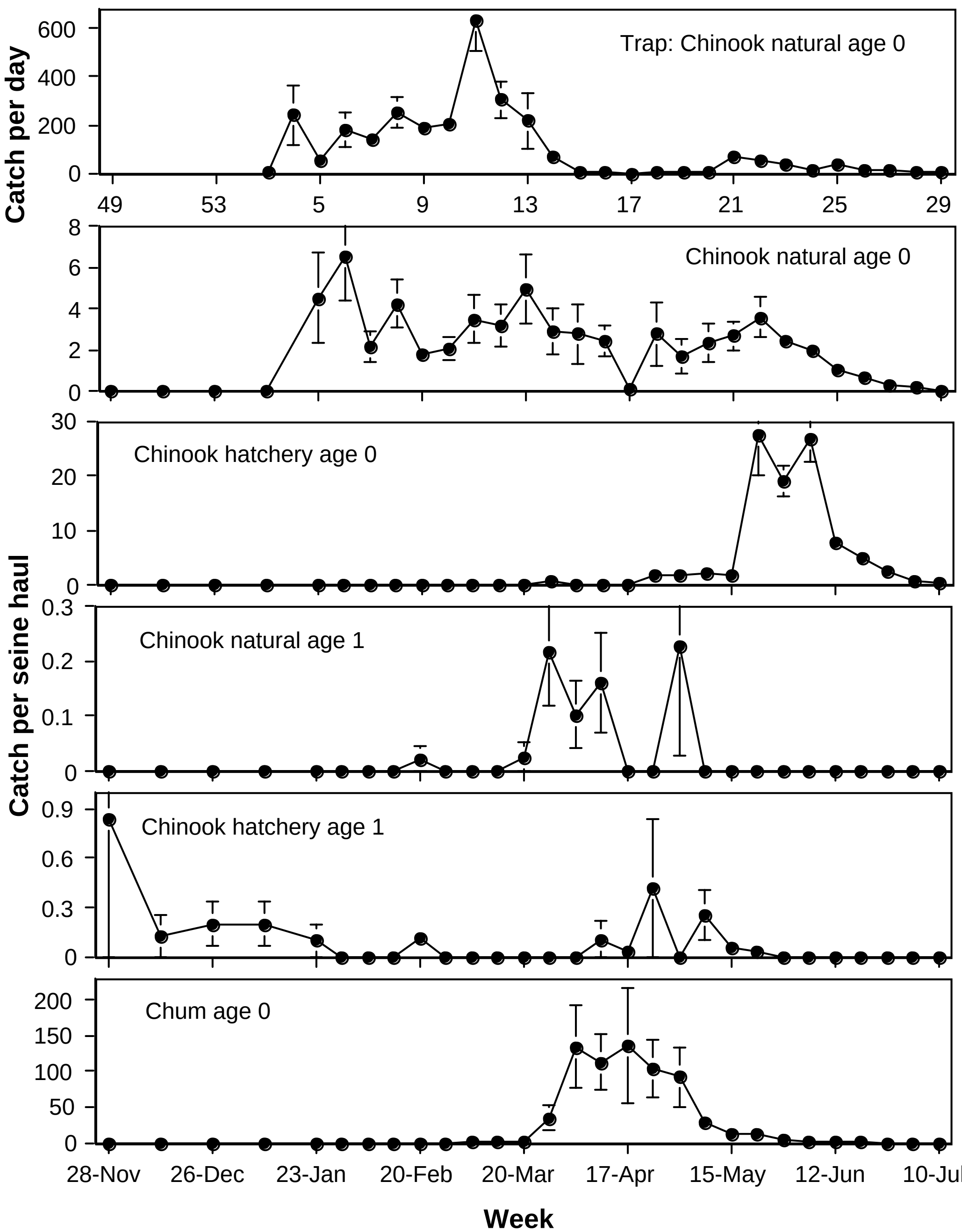


Fig. 9. Catch per effort of salmonids in the WDFW trap at RM 34.5 and in daytime seine hauls in the lower Duwamish River and estuary (RM 1 to 8.5) during December 2004 to July 2005. Values are mean ± 1 SE during each week.

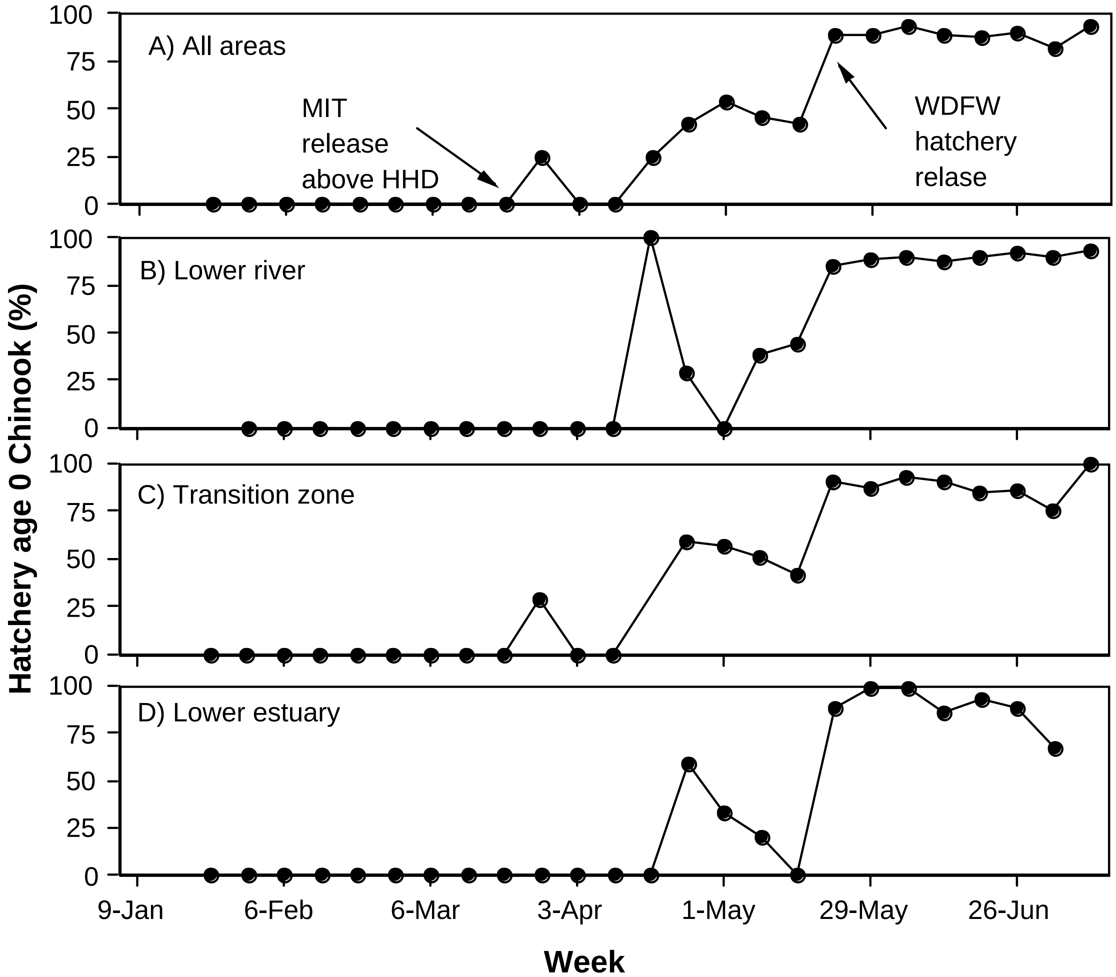


Fig. 10. Percentage of subyearling hatchery Chinook salmon among total subyearling Chinook salmon captured in all areas (A), RM 6.8 to 8.5 (B), RM 4.7 to 6.5 (C), and RM 1.0 to 3.5 (D), during January to July, 2005.

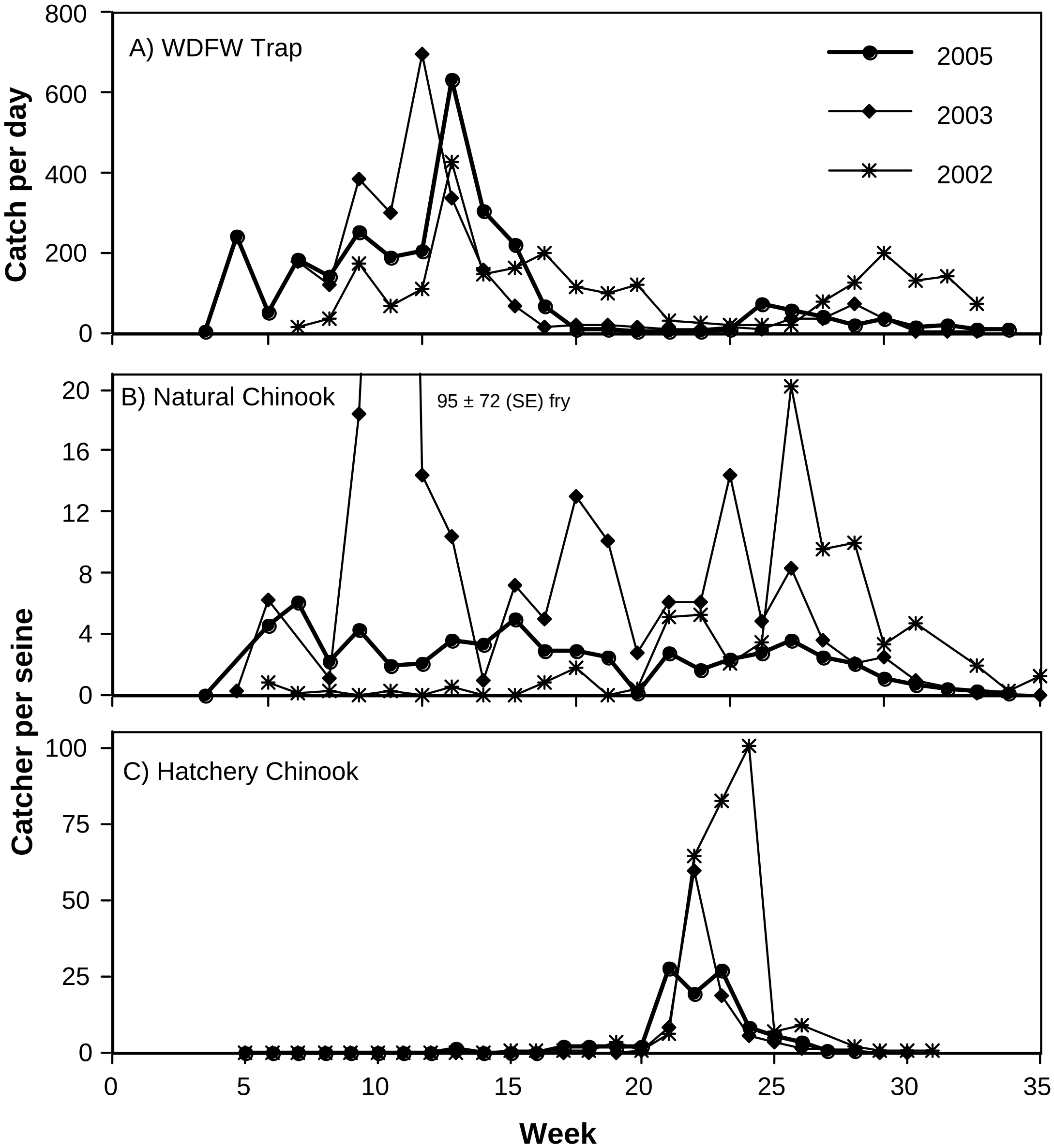


Fig. 11. Comparison of weekly abundances of natural and hatchery subyearling Chinook salmon in lower river and estuary beach seines and natural Chinook captured in the WDFW trap at RM 34.5 during 2002, 2003, and 2005. Week 20 corresponds with early May.

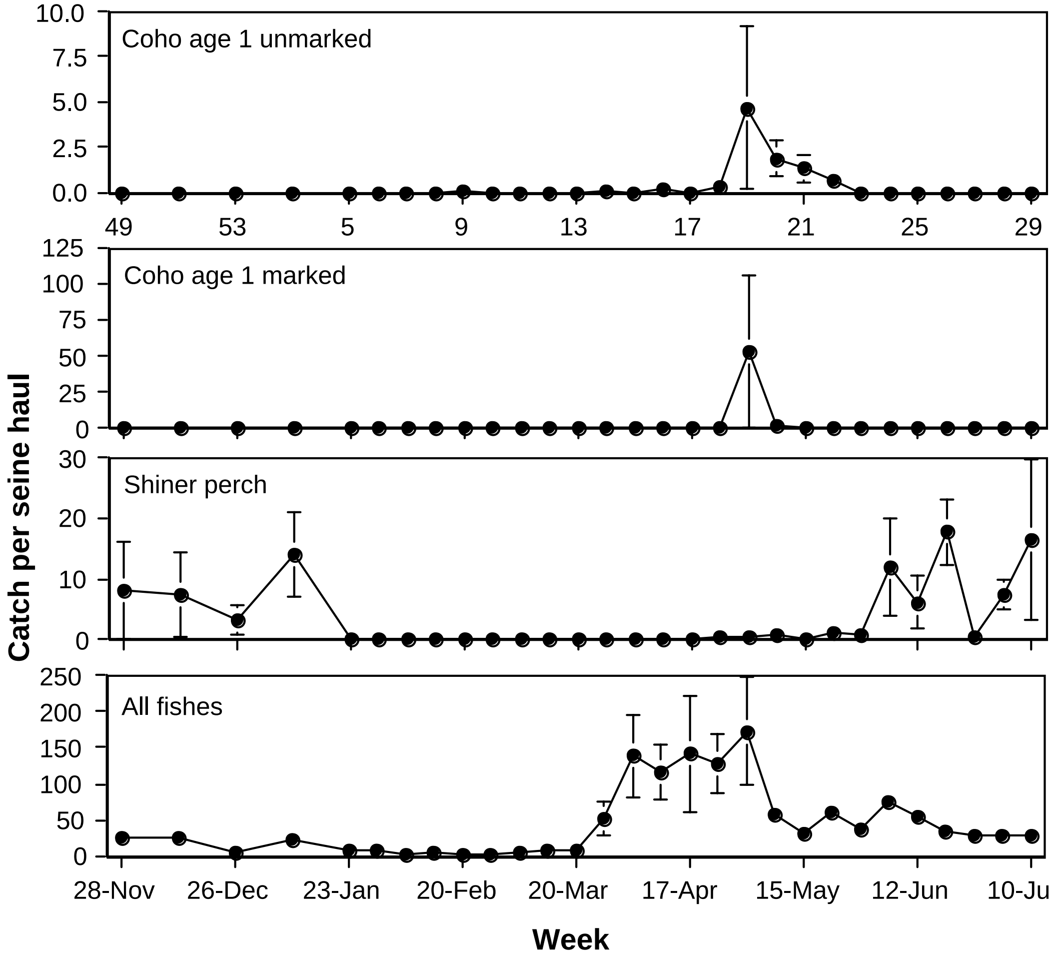


Fig. 12. Catch per effort of salmonids and other fishes in daytime seine hauls in Duwamish River and estuary (RM 1 to 8.5) during December 2004 to July 2005. Values are mean ± 1 SE during each statistical week.

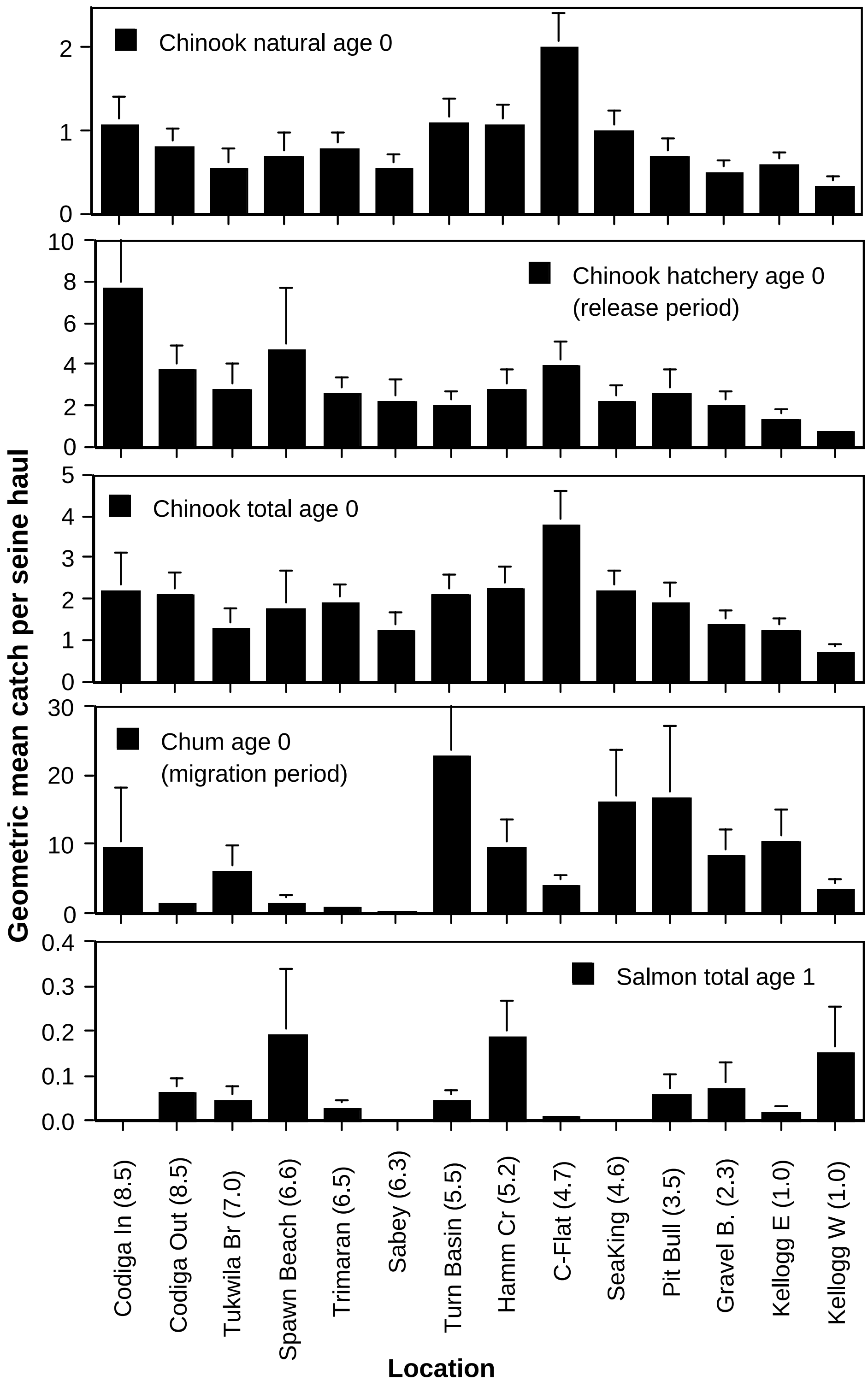


Fig. 13. Geometric mean catch of salmonids (+ 1 SE) in river seine hauls at 14 locations sampled each week, February 3 to July 12, 2005. Values for hatchery salmon only for period after release. River mile is shown with location.

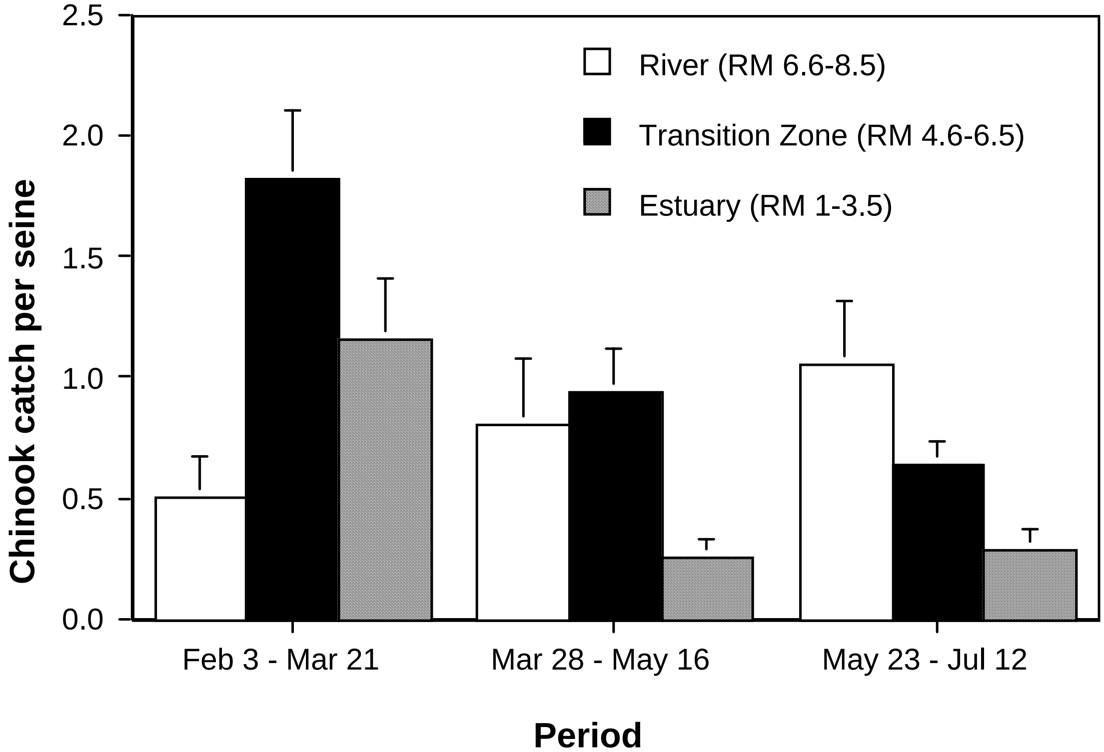


Fig. 14. Geometric mean catch of subyearling natural Chinook salmon (+ 1 SE) during each sampling period and each zone of the lower Duwamish River and estuary during 2005.

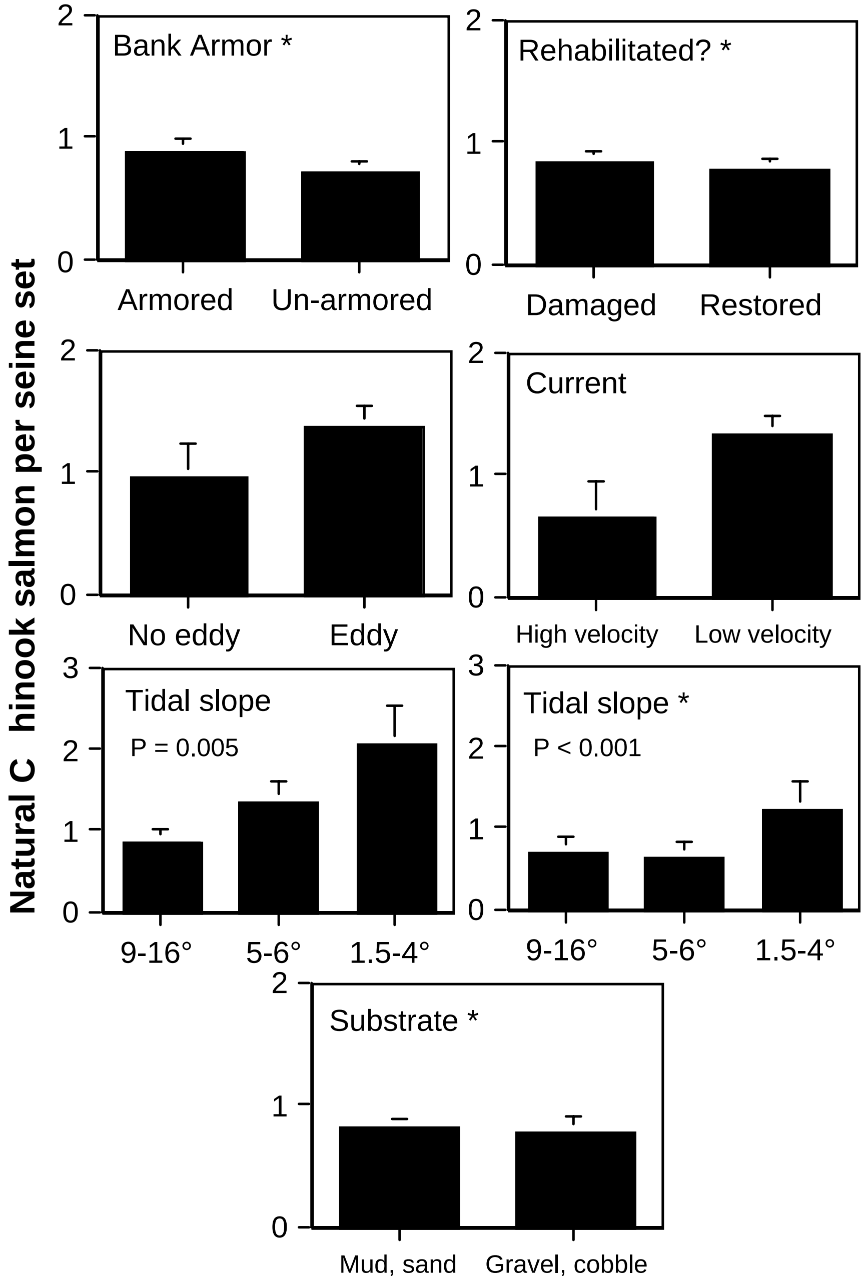


Fig. 15. Geometric mean + 1 SE of natural subyearling Chinook fry in relation to habitat characteristics. Significant differences are identified by P values. Relationships represent early migration period (February 3 to March 22) unless indicated by * as all season.

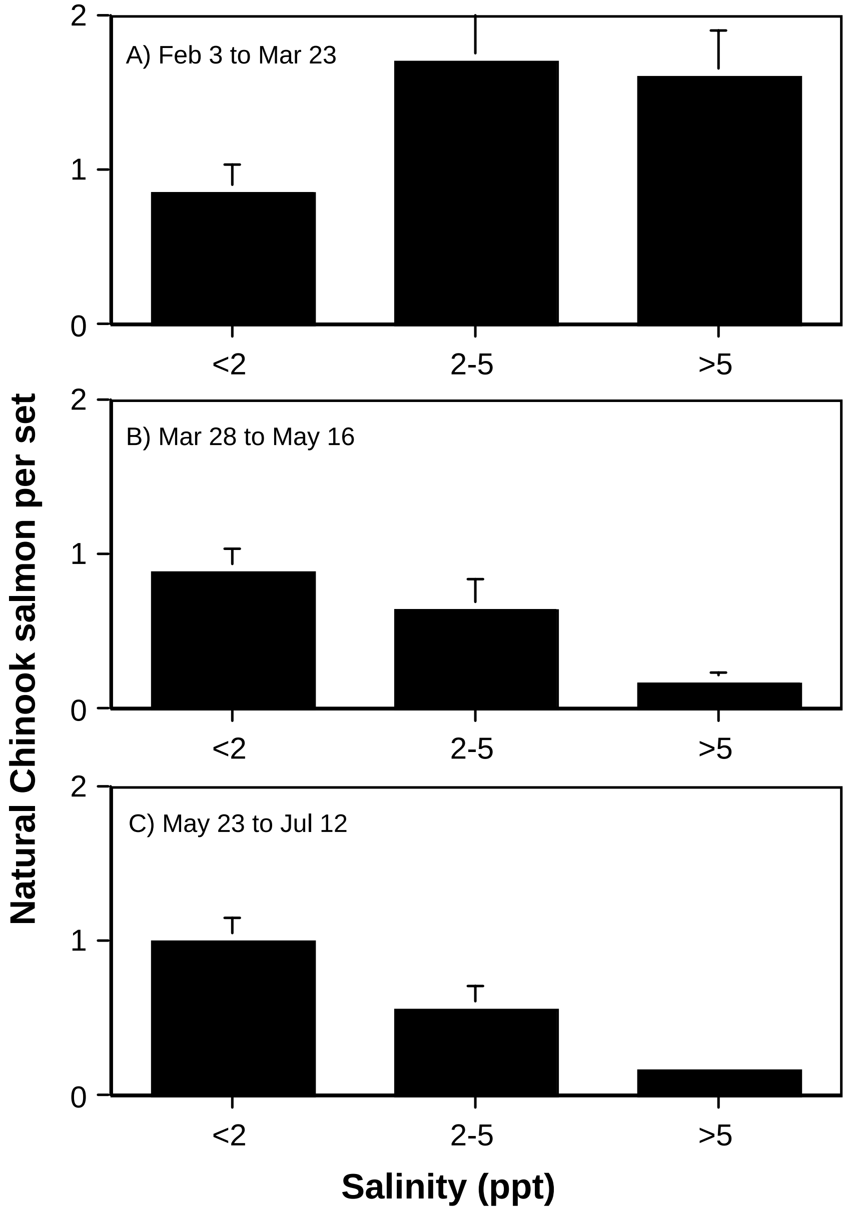


Fig. 16. Geometric mean + 1 SE of natural subyearling Chinook fry in relation to salinity (2.5 ft depth) during each period of migration.

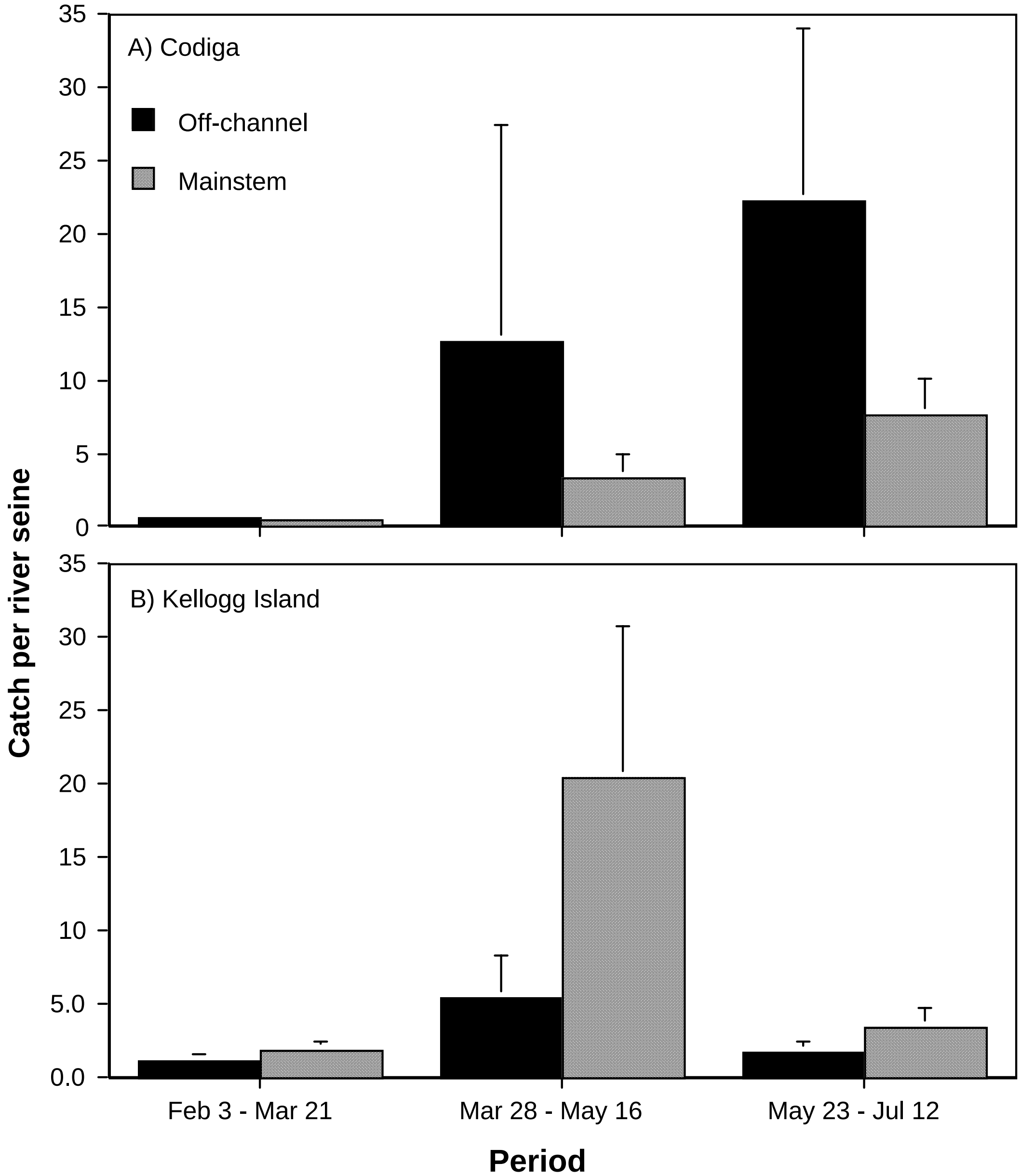


Fig. 17. Geometric mean catch of subyearling salmon (natural and hatchery Chinook and chum fry) per river seine set in off-channel vs. mainstem habitats in the lower river (Codiga RM 8.5) and lower estuary (Kellogg Island). Values are mean + 1 SE.

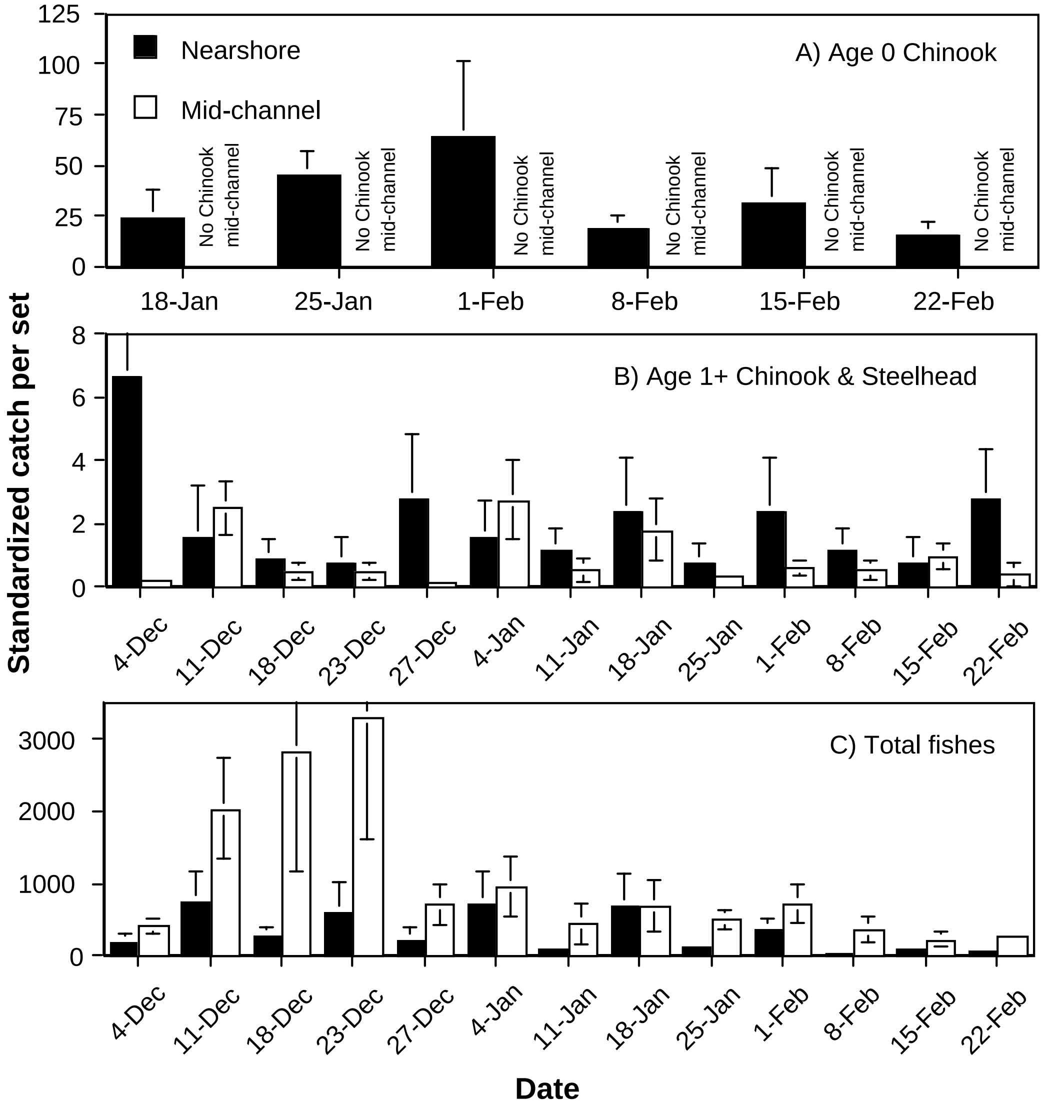


Fig. 18. Catch per set of A) age-0 Chinook salmon, B) age-1 and older Chinook and steelhead, and C) total fishes in nearshore versus mid-channel areas of the Duwamish estuary (RM 1 to 6.5). Nearshore fishes sampled with a PSP beach seine; mid-channels fishes sampled with purse seine. Catches in the smaller PSP net standardized to that of purse seine by multiplying catches by 8, which is ratio of purse seine to PSP seine surface area.

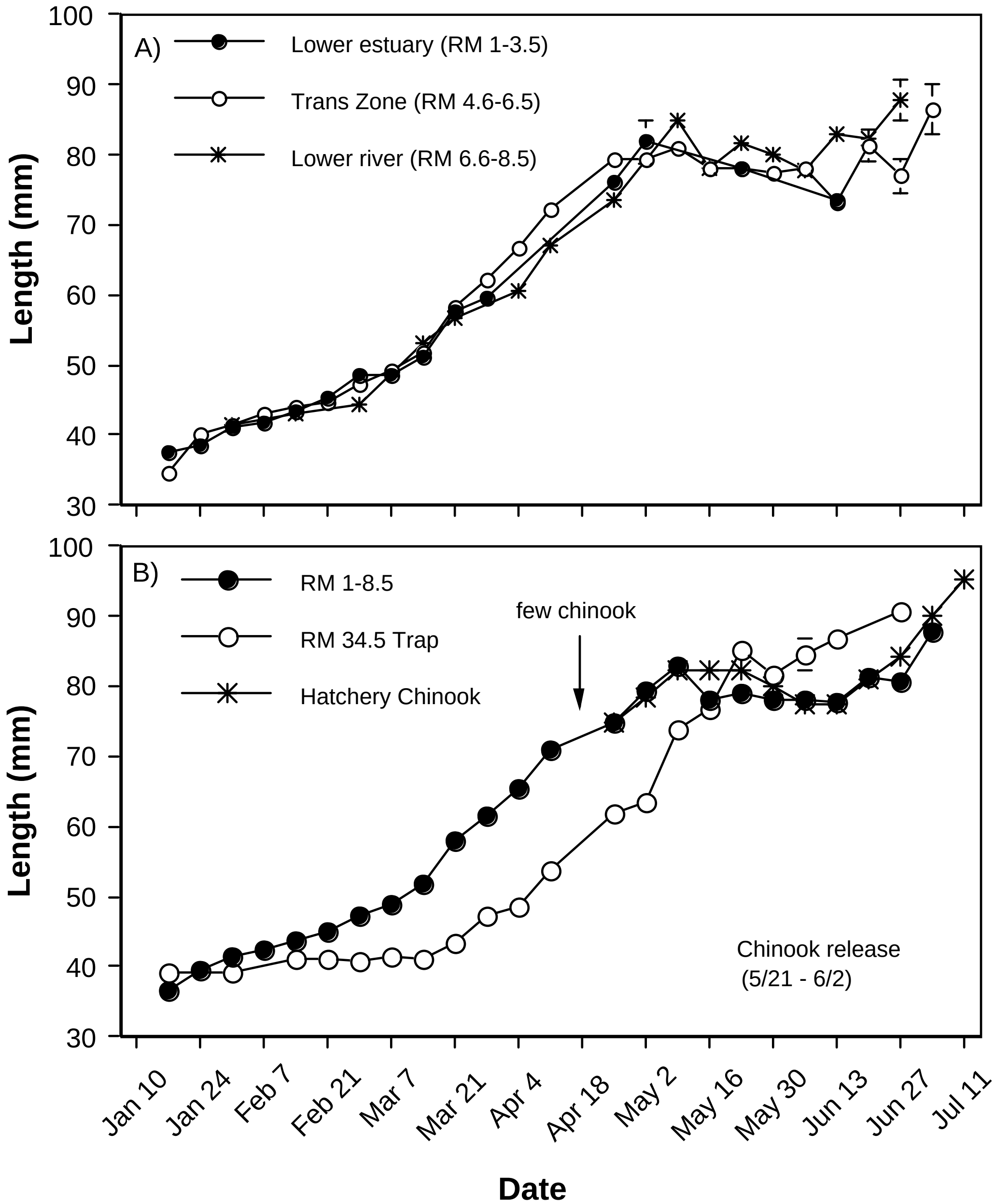


Fig. 19. Weekly length of subyearling natural Chinook salmon in (A) the three study zones (lower river, Transition Zone, and lower estuary), and (B) all zones combined compared with fish captured in the RM 34.5 trap and hatchery salmon in the lower river and estuary. Values are mean ± 1 SE of five or more fish per week per zone, or 15 or more fish in combined areas. Sample size in the lower river was 2,242 natural and 2,716 hatchery subyearling Chinook salmon.

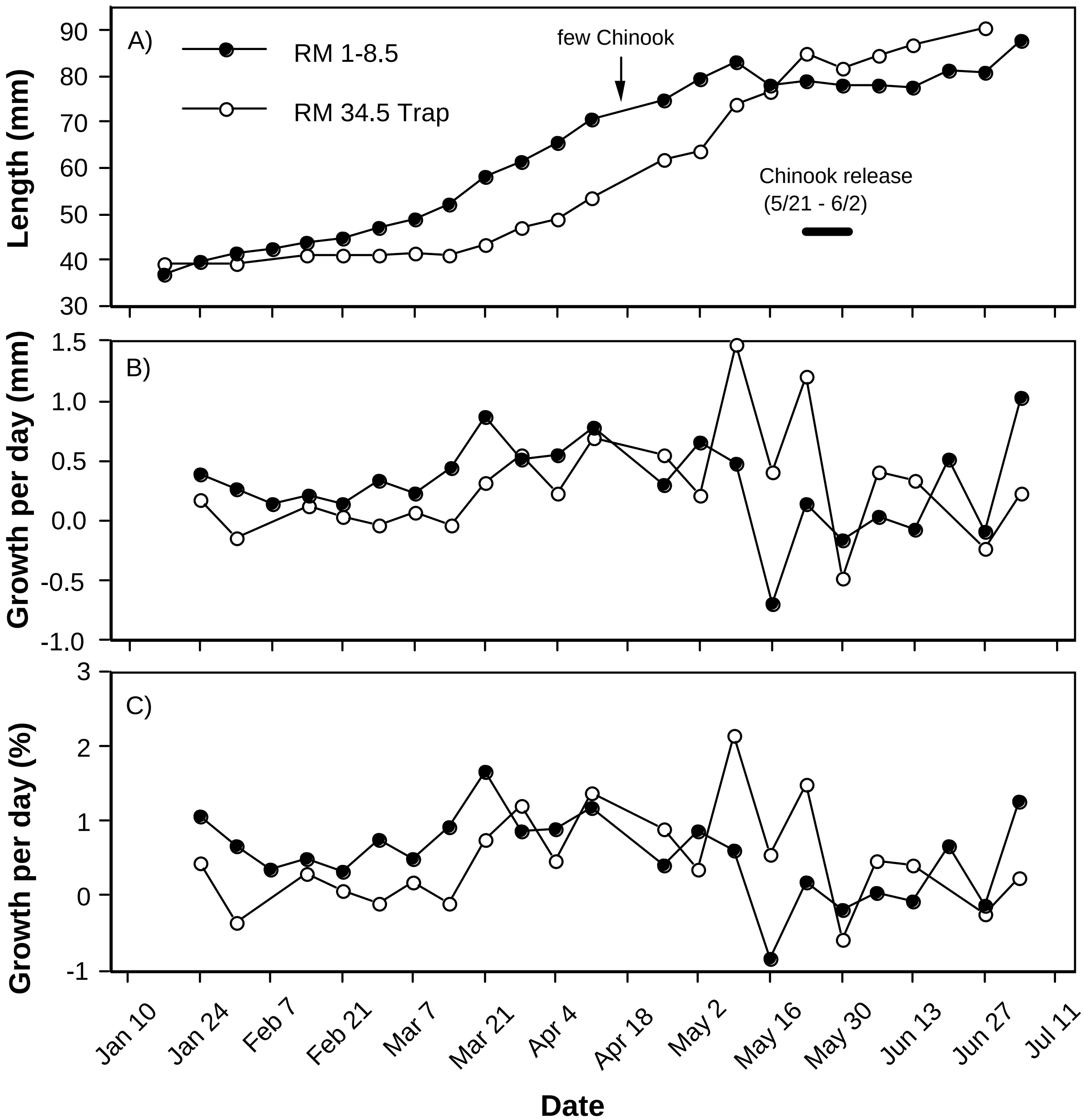


Fig. 20. Weekly length of subyearling natural Chinook salmon in (A) all zones and the RM 34.5 trap, (B) change in length per day, and (C) change in percentage length per day. Values are mean ± 1 SE. Periods of low Chinook catches and release of subyearling hatchery Chinook salmon into Soos Creek are shown.

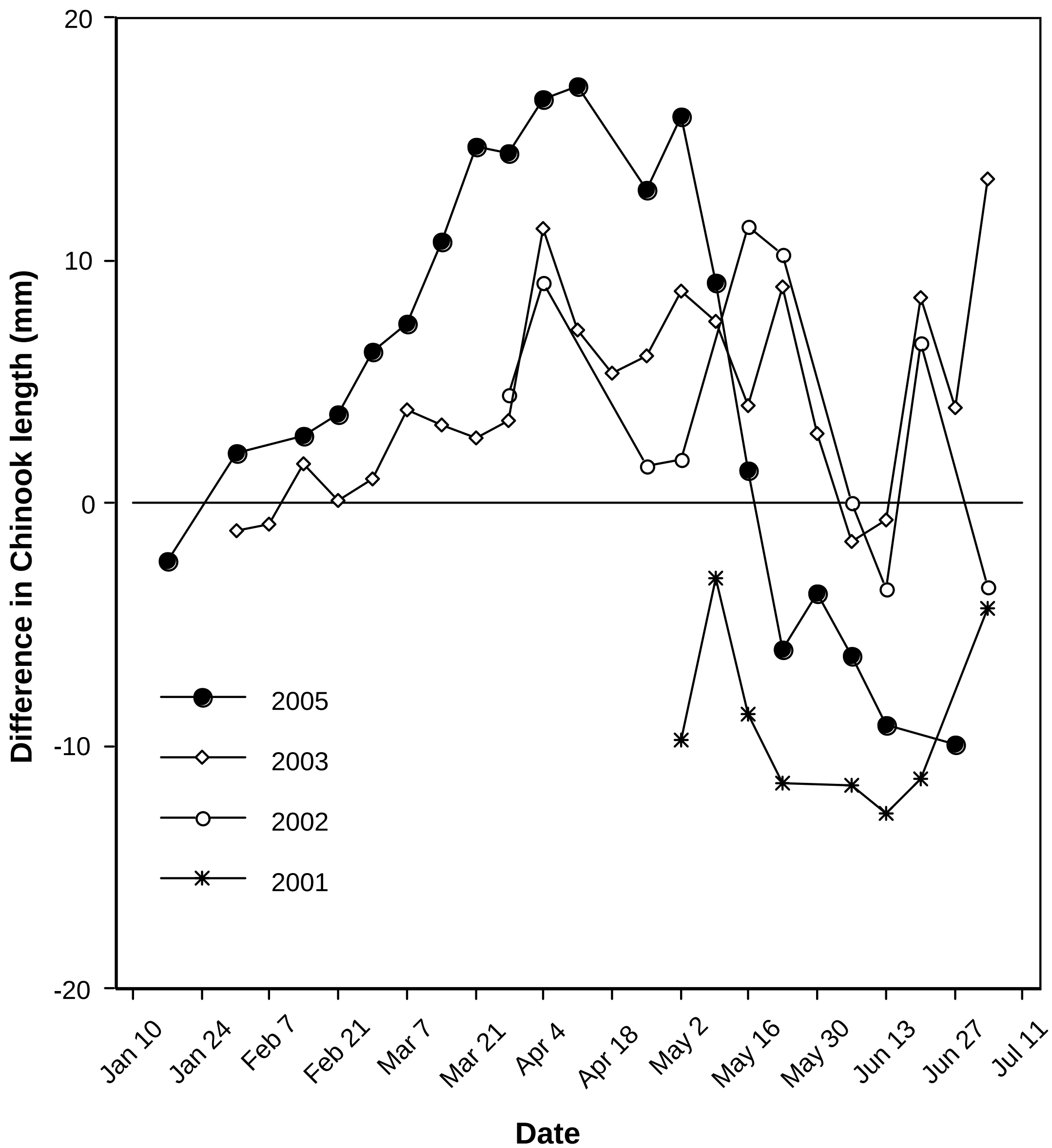


Fig. 21. Weekly mean differences in mean length of subyearling natural Chinook salmon in the lower river and estuary compared with those at the RM 34.5 trap during 2001, 2002, 2003, and 2005. Values are lower river and estuary values minus values from the RM 34.5 trap.

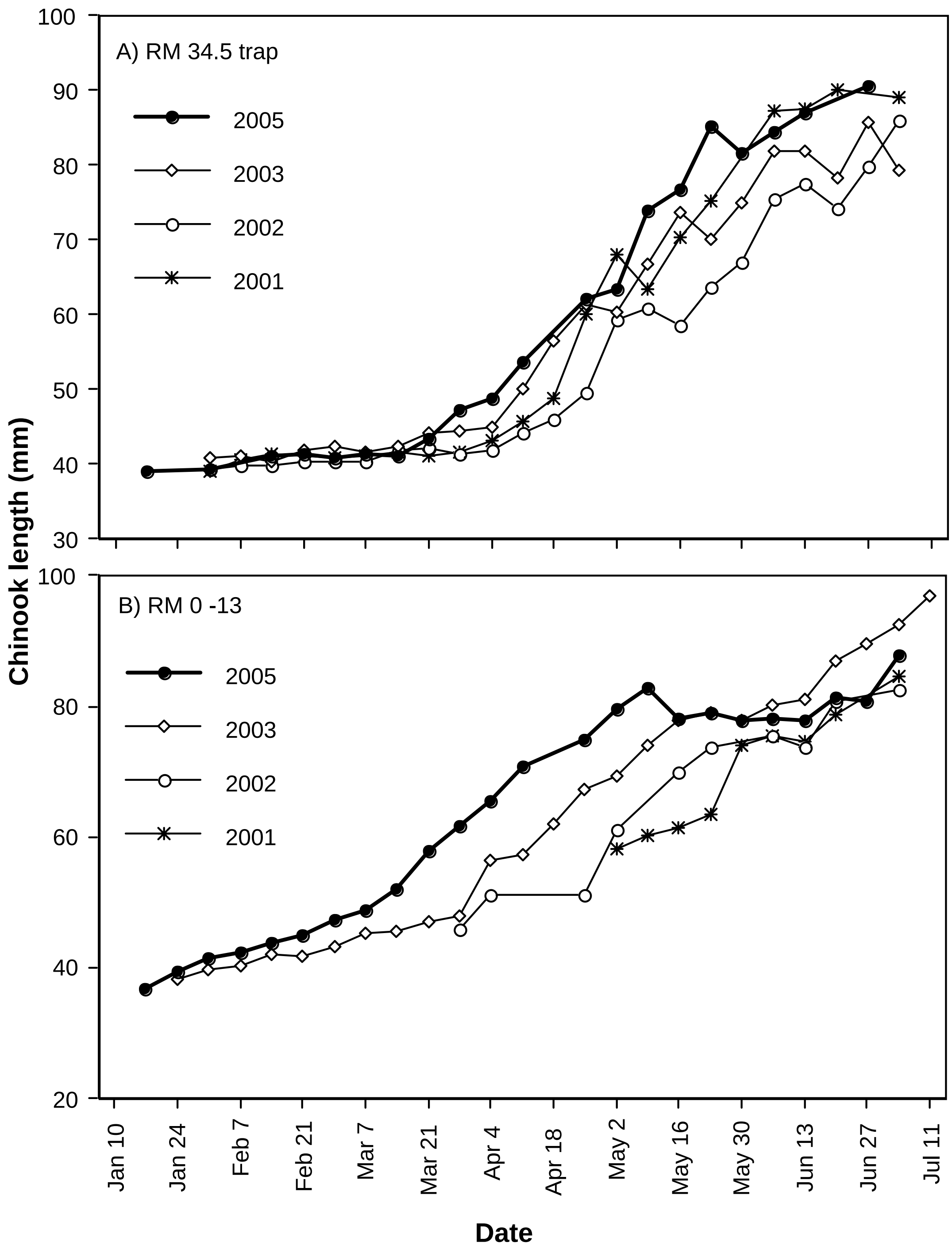


Fig. 22. Weekly length of subyearling natural Chinook salmon during each year at (A) the RM 34.5 trap, and (B) RM 0-13. See Nelson et al. (2004) for 2001-2003 data.

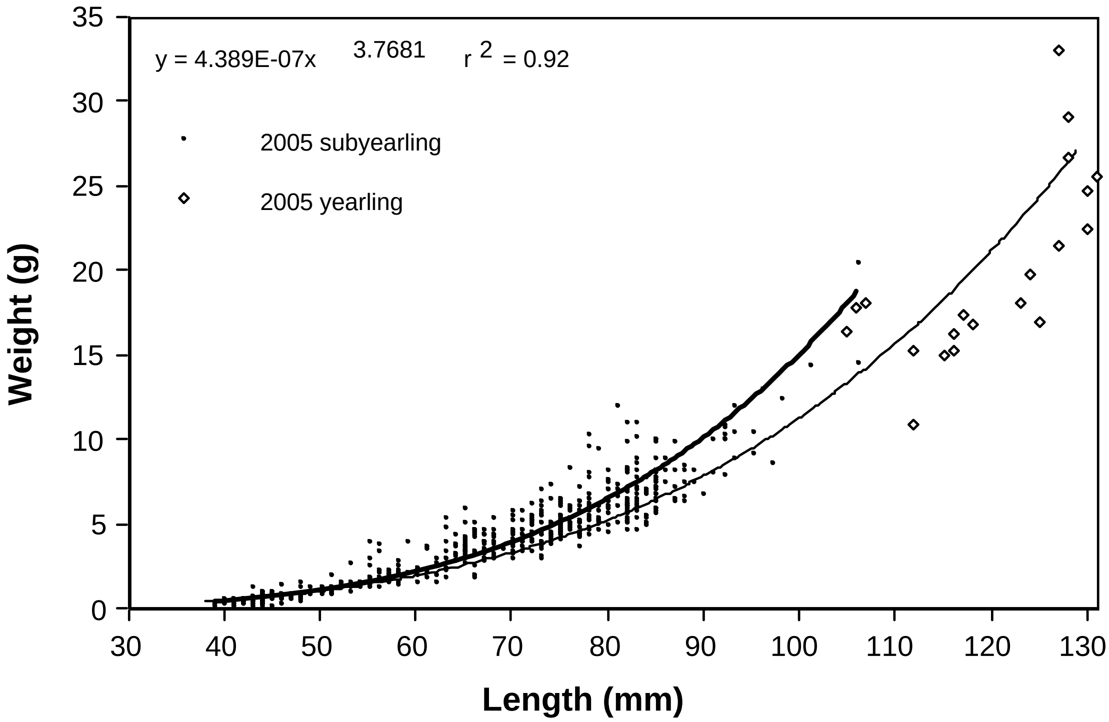


Fig. 23. Length weight relationship for natural subyearling Chinook salmon during 2005 (solid line). The relationship for hatchery fish was similar, but it is not shown. Also shown are 1) the relationship of natural subyearling Chinook during 2003 (dash line, no data points), and 2) values of yearling Chinook (<130 mm) captured during 2005 (diamond).

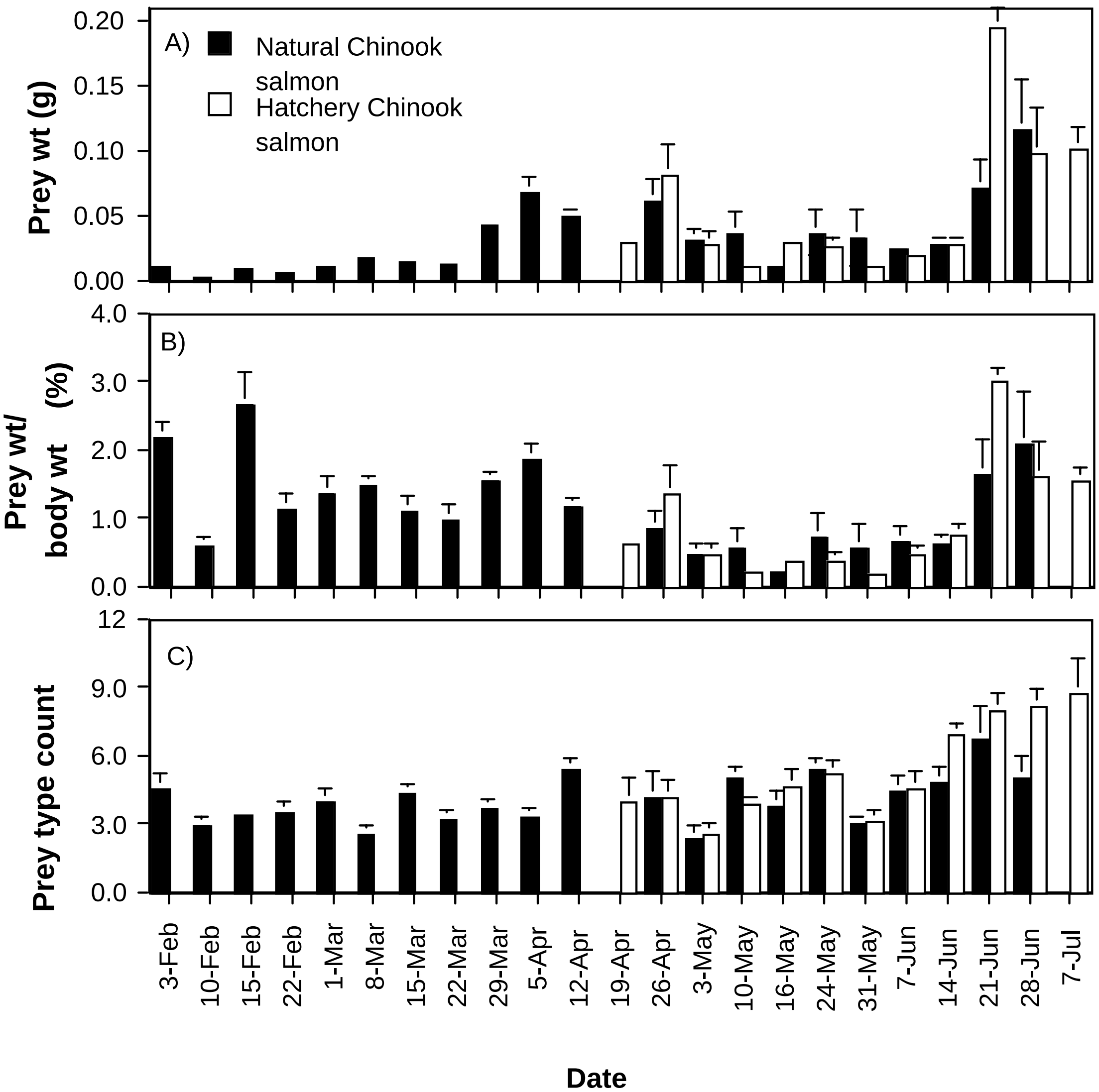


Fig. 24. Prey weight (A), percentage body weight (B), and number of unique prey types (C) consumed per natural and hatchery subyearling Chinook salmon in the Transition Zone area, January to July, 2005. Values are mean ± 1 SE. Typically 10 fish of each stock were sampled each week.

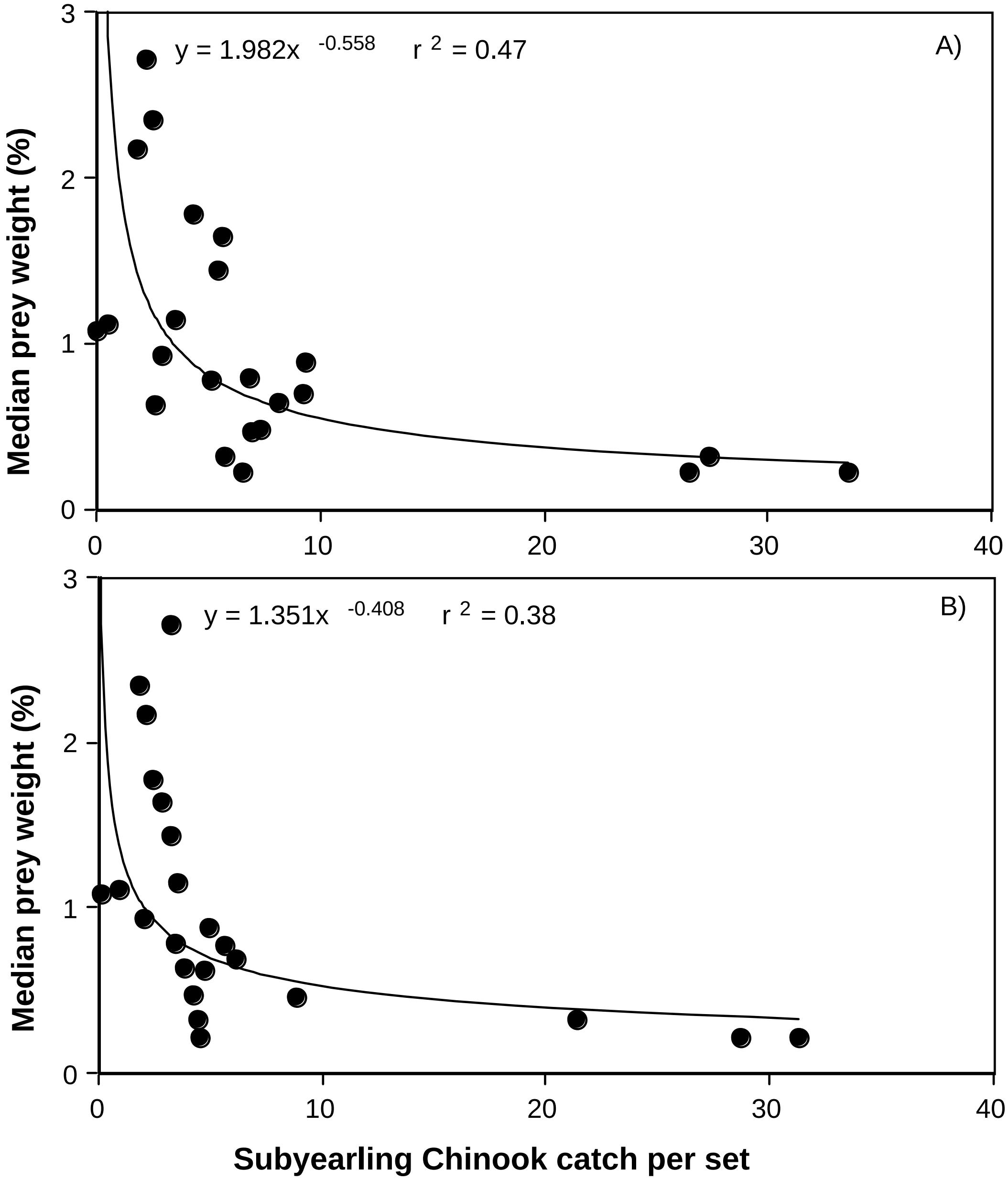


Fig. 25. Median prey weight of subyearling natural Chinook salmon captured at the Transition Zone in relation to mean weekly catch of subyearling Chinook salmon in (A) the Transition Zone, and (B) all lower river and estuary areas.

APPENDIX

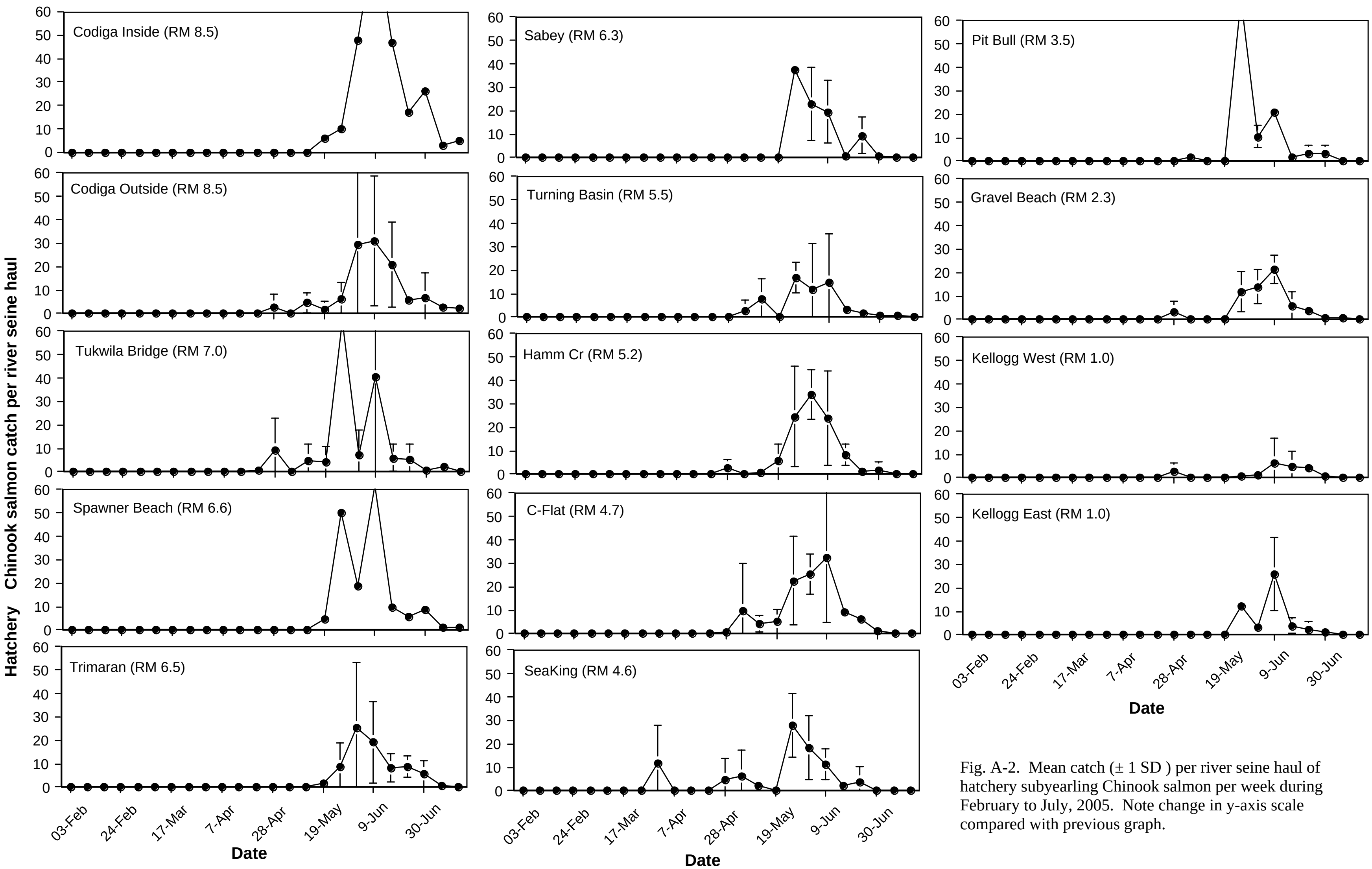
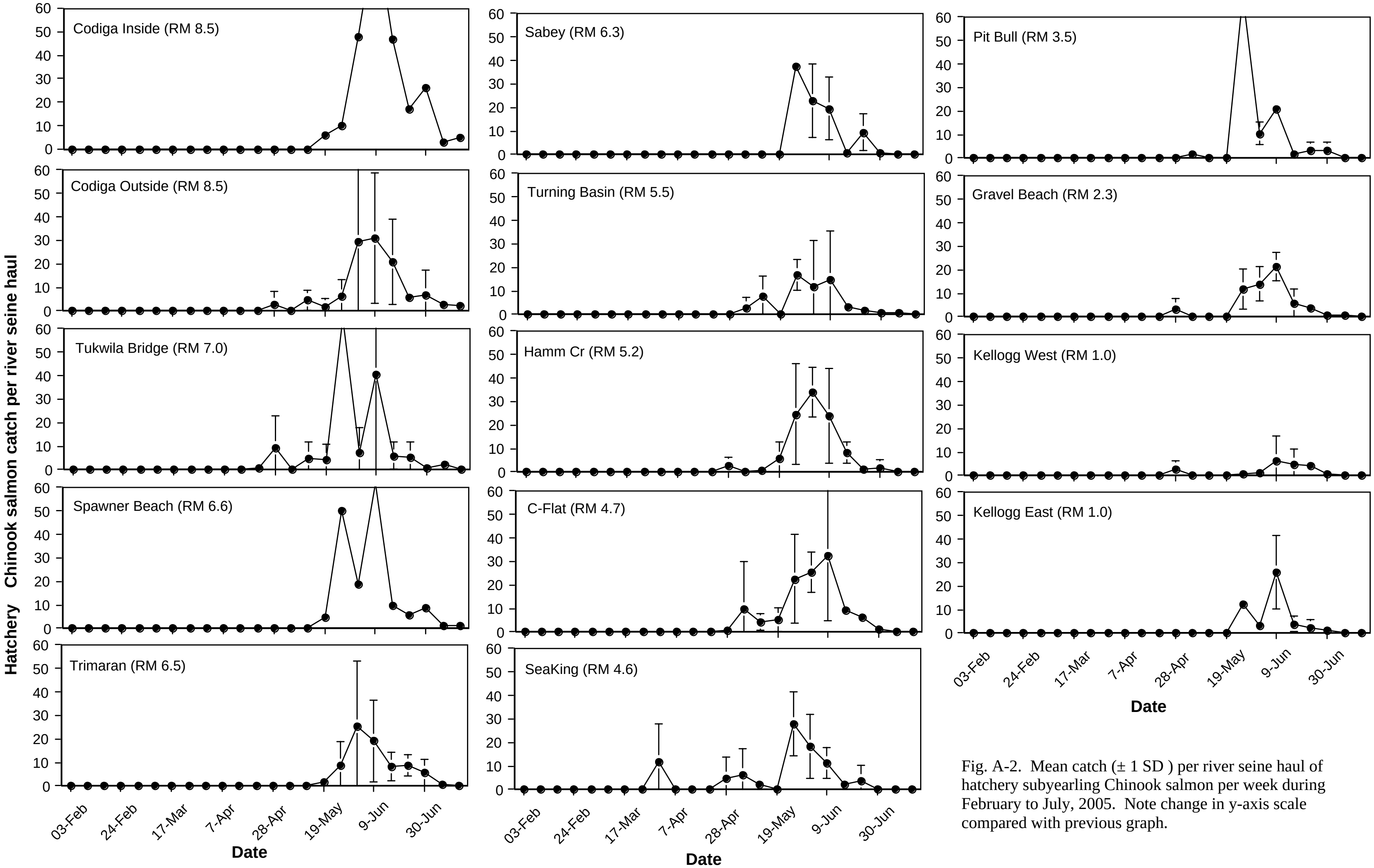


Fig. A-2. Mean catch (± 1 SD) per river seine haul of hatchery subyearling Chinook salmon per week during February to July, 2005. Note change in y-axis scale compared with previous graph.



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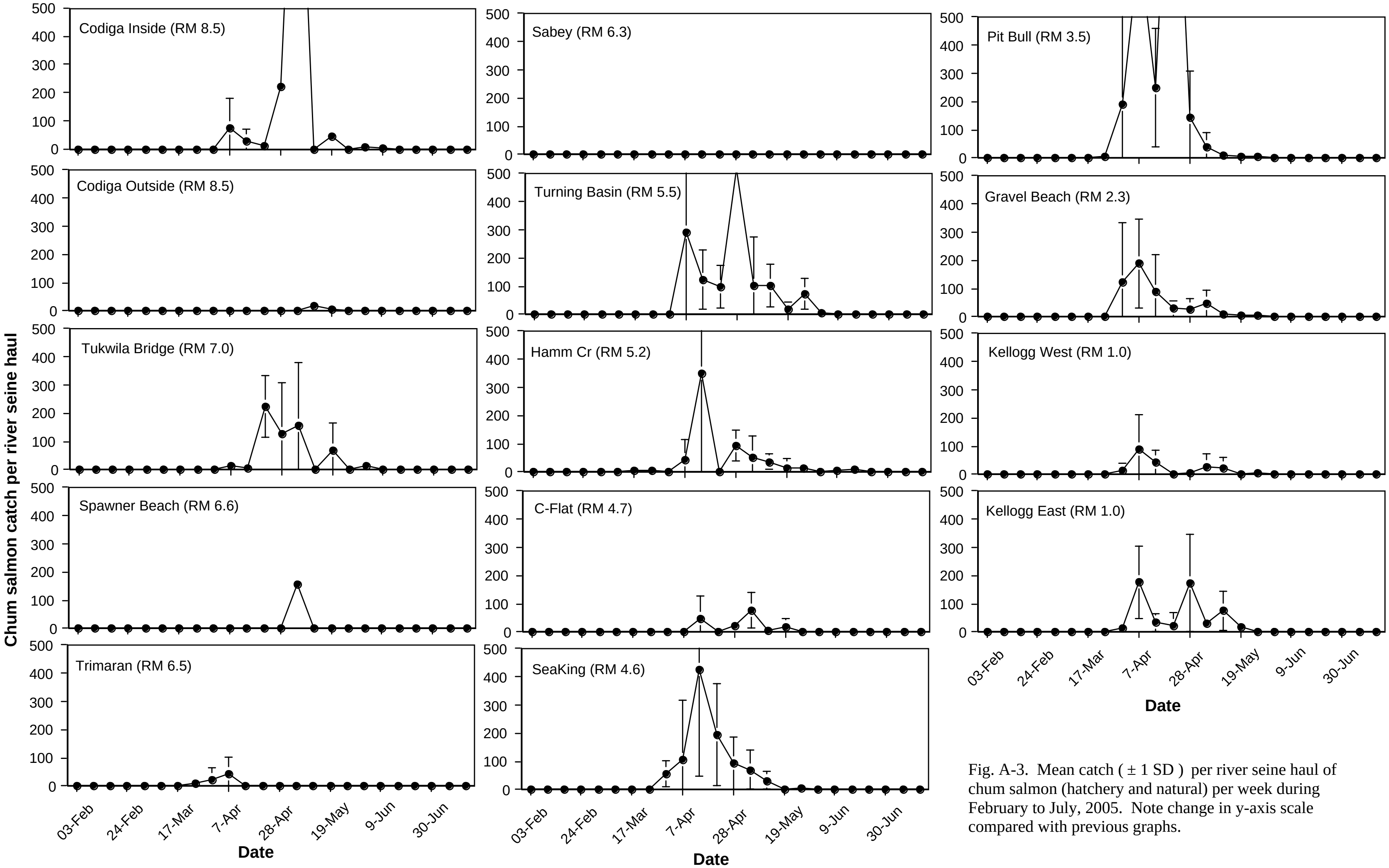

Fig. A-3. Mean catch (± 1 SD) per river seine haul of chum salmon (hatchery and natural) per week during February to July, 2005. Note change in y-axis scale compared with previous graphs.

FISH ASSEMBLAGES AND PATTERNS OF CHINOOK SALMON ABUNDANCE, DIET, AND GROWTH AT RESTORED SITES IN THE DUWAMISH RIVER

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University of Washington
SCHOOL OF AQUATIC
& FISHERY SCIENCES

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Executive Summary

Introduction

The Duwamish Waterway, once the estuary of the Duwamish River located in Seattle, Washington, is now an industrial waterway, with almost no remaining natural habitat. However, it is still an important rearing area for threatened juvenile Chinook salmon and other fish, and is also the site of a number of habitat restoration projects of various sizes and configurations. Based on previous research, these restored sites appear to be productive for juvenile salmon, but the majority of this research has been based on indirect measures of productivity, such as amounts of potential juvenile salmon prey present at the sites. These types of measures can estimate the potential for juvenile salmon benefit from a habitat, but cannot determine the probability that salmon will use the site or derive real benefits such as increased growth or survival from it. In this study we explicitly test the function of restored wetland sites vs reference non-restored sites in the lower Duwamish River for juvenile Chinook salmon by quantifying fish presence at the sites, analyzing diets of juvenile Chinook salmon using the sites, and applying bioenergetics models for juvenile Chinook salmon using appropriate input parameters.

Methods

We conducted studies at three restored sites in the Duwamish Waterway: Herring's House, in the lower, more saline part of the waterway, and Hamm Creek and Turning Basin, in the upper, oligohaline part of the waterway. The sites had different configurations and sizes, but all consisted of regraded upper intertidal habitats with planted fringing emergent vegetation. Reference sites were chosen adjacent to each restored site representing typical Duwamish Waterway shorelines retained by rip-rap, with a narrow strip of intertidal mud or sand. We sampled fish at the sites 10 times from 15 February 2005 to 8 July 2005. Measurements and samples included:

- Recording water temperatures using automated data loggers placed at each site.
- Collecting fish from each site using 60 m length enclosure nets placed at high tide, and fished just before dewatering of each site.
- Determining hatchery vs. "wild" status of juvenile salmon based on hatchery marking.
- Obtaining diets of juvenile Chinook salmon collected by non-lethal gastric lavage.
- Conducting 24-hour sampling to determine consumption rates of juvenile Chinook salmon (for use in bioenergetics modeling).

We used both parametric statistics and multivariate techniques to detect differences among sites and times.

Using the results from field sampling and from other studies, we developed and applied a modified Wisconsin bioenergetics model to test the hypothesis:

Restored sites provide increased productivity for juvenile Chinook salmon, as measured by modeled growth rates.

Summary of Findings

- Twenty three fish species were captured in the enclosure nets, with five species—shiner perch, chum salmon, threespine stickleback, staghorn sculpin and starry flounder making up the majority of the overall catch. The more marine-influenced site (Herring's House) was largely dominated by shiner perch, and had some marine fish not found at other sites, while the two lower salinity sites had more starry flounder, sticklebacks, and sculpins. However, multivariate analysis indicated that site was a less important factor than time in structuring fish assemblages, as the peak species compositions of juvenile salmonids and other fishes changed through time. In several cases, non-salmonid species were very abundant when juvenile salmon were present at the sites, and may compete with the salmon for resources.
- Although there were no statistically significant differences in overall fish densities among the sites, at two locations, Turning Basin and Hamm Creek, taxa richness was higher at the restored sites, and analysis of similarity showed that at Turning Basin and Herring's House restored and reference sites had slightly different fish assemblages.
- The only statistically significant difference we found for juvenile salmon among paired restored and reference sites was at the Turning Basin, where juvenile Chinook were significantly more abundant at the restored site. This may be because this site has a relatively unobstructed opening to the main channel of the Duwamish estuary making access easier, or because the salmon densities and residence are greater in the Turning Basin area than in other parts of the estuary and restored site use is density dependent.
- Juvenile Chinook salmon in this study fed on a variety of benthic invertebrates, terrestrial insects, and emergent marsh insects, similar to results from previous studies. Juvenile Chinook had markedly and consistently higher instantaneous ration of food at both the restored and reference Turning Basin sites compared with the other two study sites. This higher ration also translated into higher modeled growth rates at the Turning Basin as compared to the other locations, when the model consumption rate was adjusted for instantaneous ration. These findings could be the result of either more intensive fish foraging there or better prey availability in the area, and they suggest that the benefits to juvenile Chinook salmon of locating future intertidal habitat restoration projects near the Turning Basin may be high.
- The bioenergetics models did not verify our hypothesis that restored sites provided juvenile Chinook salmon with enhanced growth potential: modeled growth rates were similar among the restored and reference sites or were inconsistent among sites and months. This may indicate that prey is not limiting for juvenile Chinook salmon in the lower Duwamish River, and that they acquire adequate food throughout the waterway. Other factors may include lack of precision in the models due to inability to adequately measure in situ consumption rates, or the relatively short time fish were held on the site by the enclosure nets.

Fish Assemblages and Patterns of Chinook Salmon Abundance, Diet, and Growth at Restored Sites in the Duwamish River

Introduction

An important goal of salmon recovery in the Puget Sound region is to identify and implement habitat rehabilitation projects that will most effectively enhance the viability of Puget Sound Chinook salmon. Prior to implementing these projects, information is needed on how and where Chinook salmon utilize existing habitats and on the benefits of previously restored habitat.

The Duwamish Waterway is the highly industrialized lowest reach of the Duwamish River (Fig. 1). Despite being profoundly impacted, the waterway still harbors outmigrating juvenile salmonids, and research in 2002 and 2003 indicated that densities of juvenile Chinook salmon and other salmonids were relatively high in the vicinity of the Turning Basin, the upstream extent of channel maintenance (sample sites at RM 5.5 and 6.5) (Nelson et al. 2004). It was hypothesized that fish aggregate there because it forms a transition zone where fresh and marine water mix and where the fish first encounter large eddies and shallow, slow-moving water.

Previous research did not locate the boundaries surrounding regions of high salmon density in the lower Duwamish River, and documenting these boundaries was identified as a top priority by the WRIA 9 Research Framework and the WRIA 9 Technical Committee because rehabilitation projects might be most beneficial if they targeted areas where Chinook salmon are known to aggregate. It was also deemed desirable to have additional data supporting or refuting the transition zone hypothesis, and to identify habitat features associated with high abundances of juvenile Chinook salmon. If fish are randomly distributed, then habitat rehabilitation projects might benefit salmon anywhere along the Duwamish River where the opportunity exists. On the other hand, if the juvenile salmon aggregate in certain reaches and/or associate with particular habitats, these areas can be targeted in restoration/rehabilitation design.

Growth is an important determinant of Chinook salmon survival, and enhancing growth potential is an important component of habitat rehabilitation. Larger salmon are more likely to avoid predators and may have greater probability of surviving winter when prey availability is low (Beamish and Mahnken 2001, Nagasawa 2000). Recent data from coded-wire-tagged Chinook salmon indicated their survival was significantly lower when their growth in Puget Sound and the lower Strait of Georgia was reduced in response to competition with pink salmon (Ruggerone and Goetz 2004). Juvenile wild Chinook salmon growth rates may be compromised in the lower Duwamish because it is highly altered with little remaining natural estuarine habitat, and because more than 3 million hatchery Chinook salmon are released into the river yearly, potentially competing with the wild fish. Research in 2003 suggested that growth of Chinook salmon in the Duwamish was reduced during periods of high Chinook densities (Nelson et al. 2004) and that residence time of Chinook salmon in off-channel habitats significantly declined when numerous hatchery salmon were released into the watershed (Ruggerone and Jeanes 2004). Although these studies were only conducted in one year, and were limited by some of their assumptions (e.g., that salmon size increase was due to growth and not emigration), they point to the need to further understand salmon distributions, residence, growth, and habitat use in the lower Duwamish.

The WRIA 9 Technical Committee (W9TC) received grant funds from the Salmon Recovery Funding Board and the King Conservation District to conduct a habitat assessment and utilization study in the Lower Green River, Duwamish Estuary and Marine Nearshore of Central Puget Sound. The W9TC prioritized these data gaps and identified the following hypothesis as a top priority for 2005 research efforts (Ruggerone et al. 2004):

- The upper estuary (Turning Basin and adjacent areas, ~RM 5.5-7) is a key rearing habitat that supports both fry and fingerling outmigrating juvenile Chinook salmon with adequate habitat capacity.

The W9TC also identified two additional topics to be addressed in 2005 using the grant funds. The first topic was general salmonid distribution and timing in the lower Duwamish, which is addressed in an accompanying report. The second topic was habitat site productivity, which we address in this report. The primary goal of this study was to determine the relative productivity of restored vs. non-restored habitat for juvenile Chinook salmon in the lower Duwamish Waterway. Using bioenergetics modeling, the following hypothesis was tested:

> **Restored sites provide increased productivity for juvenile Chinook salmon, as measured by modeled growth rates.**

The Duwamish "estuary", where fresh and marine water mix, is located in the industrial waterway, where there is almost no remaining natural habitat. However, it is also the site of a number of habitat restoration projects of various sizes and configurations. Some of these sites have been periodically monitored for biological attributes important to juvenile salmon and for use by the salmon themselves, and they appear to be productive relative to reference sites (Cordell et al. 1999). However, the majority of this monitoring has involved indirect measures of productivity, such as amounts of potential juvenile salmon prey invertebrates present at the sites. This type of "opportunity" measure appraises the capability of juvenile salmon to access and benefit from a habitat, but does not allow for a determination of the probability that salmon will use the site or derive any realized function (e.g., growth) from it (Simenstad and Cordell 2000). In this study we explicitly test the function of restored wetland sites in the lower Duwamish for juvenile Chinook salmon by measuring or estimating temperature, prey quality and quantity, and consumption rates, and applying the results to a bioenergetics model.

Material and Methods

Study Sites

Three pairs of restored/reference sites were selected, each consisting of an off-channel restoration site with an adjacent reference site along the main river channel (Fig. 1). The following restoration sites were sampled (descriptions are summarized in part from the National Oceanic and Atmospheric Administration Damage Assessment and Restoration Program Website at http://www.darp.noaa.gov/northwest/elliott/restore.html:

1. The Herring's House restoration project is located at river mile 2 on the site of a former lumber mill that operated from around 1929 until the early 1980's. The site is on the only relict river oxbow, and near Kellogg Island, which is one of the only undeveloped habitat patches in the system. The restoration site is approximately 17 acres in size, with six acres of upland and eleven acres of intertidal habitat. An outer berm consisting of 8-9" quarry stone and fish rock (fine/medium gravel and coarse sand to 3/8 inches) was constructed in 1999. Structures, pilings, paving, and highly contaminated soil were removed, and clean soil and containment features were added. A 1.8-acre intertidal bay of elevations between +6 to +12 feet MLLW was excavated, and protected by two armored spits forming a mouth opening to the Duwamish River. An amended on-site soil mixture of silts and clays with a high organic content was distributed to a depth of 18 inches over the basin, and the slopes were planted with emergent marsh plants at various elevations. Native scrub/shrub riparian vegetation was planted on the banks and uplands. The primary goal was to provide juvenile salmon with a low-energy intertidal environment that would provide refuge and invertebrate food sources.

2. Hamm Creek is a small stream that joins the west side of the Duwamish River just downstream from the head of the dredged city waterway at approximately river mile 6.2. Historically, Hamm Creek meandered through an intertidal marsh before entering the river. From the early 1950's through 1971 the site was used as a dredged material stockpiling area. During this period and prior to the restoration project, it had been routed alongside a road for approximately 1100 feet, and then into a ~1300 foot culvert underneath a boat fabrication business (Delta Marine Industries), and emptied into the river through the same culvert. The restoration effort had the two general goals of 1) restoring important estuarine habitat and 2) improving fish passage and habitat in the freshwater portion of lower Hamm Creek. The restoration site is a 6.2-acre parcel of land within the 21.5-acre Duwamish Substation property owned by Seattle City Light. Construction started in July 1999 and the project was completed in the year 2000. The project was constructed by the U.S. Army Corps of Engineers and King County and consisted of (1) removal of approximately 60,000 cubic yards of historical dredge material at the mouth of the creek, and creating a low-gradient intertidal estuarine wetland and an adjacent freshwater marsh; (2) removing the terminal culvert at the mouth of the creek and "daylighting" the underground portion of the stream; (3) creating a "natural" stream-course, with meanders, fish pools, and large woody debris, for the daylighted section and to replace the straight-line open section of creek that paralleled the road; and (4) planting a new riparian buffer of trees and shrubs along the new stream course. The goals of the project were to provide a more accessible entry to Hamm Creek for salmonid spawning, and to create new riparian stream and intertidal estuarine marsh habitats that will provide refuge and prey resources for juvenile fish.

3. The Turning Basin site is located at the upstream boundary of the maintained navigation channel, and is where the Duwamish River enters the industrialized waterway. The upland portion of the site was composed of fill material and was covered with asphalt and concrete pads, in addition to a light industry building and storage facilities. The restoration was conducted by the Port of Seattle in 1999 and consisted of (1) removal of commercial structures and foundations; (2) recontouring and revegetating the uplands to create an enhanced riparian zone; and (3) creating an intertidal flat, fringed by native emergent plants. This site now consists of an upland riparian buffer planted with native trees and shrubs and a regraded upper intertidal basin planted with fringing native sedge, *Carex lyngbei*, and rush, *Scirpus maritima*.

Reference sites were chosen adjacent to each restored site representative of typical Duwamish Waterway shorelines retained by rip-rap, with exposed mud/sand flats at lower tides. Sampling was conducted during consecutive spring tides 10 times from 15 February 2005 to 8 July 2005.

Enclosure Nets

All three of the restoration sites dewater at mid-tide, and are only accessible by fish at relatively high tides. Fish sampling took place during these inundation periods at each restoration and reference site, using enclosure nets (Fig. 2). Nets were deployed during high Spring tides, and were sampled for fish as the sites dewatered at low tides. Nets were 60-m long and 4-m deep, with a 0.64-cm mesh net. At the restoration sites the net was used to block the mouth of the restoration site, enclosing each site in its entirety. At reference sites the nets were placed around poles or with weights to enclose a 20-m^2 rectangular section of the shoreline. Fish were removed with either a small pole seine (1.2-m. x 9.1-m., 0.64-cm mesh; Fig. 3) or dip nets as the tide receded, usually starting at mid-tide a few hours after net deployment. All fish were removed before low tide (Fig. 4). Non-salmonid fish captured in the net were identified, counted, and released. Hatchery and wild status of salmonids was determined by recording hatchery-clipped adipose-fins and testing with coded-wire tag readers. We refer to "marked" as those positively identified as hatchery releases by one of the above methods, while "unmarked" salmon refers to fish with intact adipose fins and no coded-wire tags. Although unmarked salmon are usually assumed to be wild fish, incomplete marking can complicate this determination. Forklengths, weights, and diets of salmonids were sampled to at least n = 5 for each of the following categories: (1) species, (2) marked or unmarked status, and (3) size class (Fig. 5). Standard lengths of all other fish were recorded for at least 20 individuals.

Diets of juvenile salmonids were sampled by gastric lavage (Fig. 6). This method consisted of placing fish in a tray of seawater with a small amount of the anesthetic MS-222 for approximately 30 seconds. Each fish was removed from the tray and measured for forklength and weight. Gut contents were then removed using a modified garden pump sprayer with a custom nozzle and filtered seawater. Gastric lavage has been shown to result in 100% removal of food items and to have no adverse long-term effects in salmonids (Twomey and Giller 1990). Contents were washed into a 106-μm sieve and fixed in 10% buffered formaldehyde solution. Fish were immediately placed in a bucket of seawater for recovery (approximately 2-3 minutes), and then released.

Enclosure net sampling produced per unit area densities of fish for each unit of shoreline sampled. The main benefits of using enclosure nets as a comparative technique between the restoration and the reference sites were: (1) The entire water column was sampled, providing comparable density estimates; densities from techniques such as beach-seining can be compromised by varying sampling efficiencies over different substrates and water depths (Rozas and Minello 1997), and (2) the enclosure nets held the fish at each site for several hours, making fish diet analysis more representative of feeding at each site, instead of an "instantaneous" measure that is provided by beach seining. The major drawback of comparative sampling between restoration and reference sites was that the sampled area was different at each site, due to different site configurations. Densities were standardized by unit area, as follows: all reference sites 0.1 acre, Turning Basin 1.3 acre, Hamm Creek 0.7 acre, Herring's House 2.1 acre, (USFWS 2004, Simenstad et al. 2005).

Each time an enclosure net was deployed, the following environmental measurements were taken: (1) surface and bottom water salinities and temperatures were recorded with a portable YSI meter, (2) total amount of time the net was deployed before complete fish sampling, and (3) maximum water depth at time of net deployment at high tide.

In the laboratory, salmonid prey items from gastric lavage were identified using a dissecting microscope. Small benthic and planktonic crustaceans and a few other taxa were identified to genus or species. However, for other major prey items such as insects, identification was only practicable to the order or family level. Each prey taxon was weighed to the nearest 0.0001g. All samples were assigned a digestion rank (1=no prey identifiable, 6=all prey identifiable) based upon the proportion of the sample which was identifiable. Additional diets of salmonids from the area surrounding the Turning Basin were also analyzed; these preserved fish were obtained through the beach seine component of the overall project.

Statistical Analysis

Data was entered in Microsoft Excel and analyzed using S-plus (univariate statistics) and Primer version 6 (multivariate statistics) software (Clarke and Warwick 2001). Analysis of variance (ANOVA; alpha = 0.05) was conducted to analyze log-transformed densities of juvenile Chinook salmon and total fish densities at each pair of restored and reference habitat types. Multivariate data analyses were employed to examine the similarities of the overall fish community among sites and times. Fish abundance data was analyzed with nonmetric multidimensional scaling (NMDS) ordination, analysis of similarity (ANOSIM), and similarity percentage (SIMPER) analysis. These analyses uncover patterns in multivariate groupings of the data (Clarke 1993), which is helpful when analyzing datasets with multiple species compositions. Densities were log-transformed for ordination, with hatchery and wild status of salmonids combined, and species that did not account for more than 2% of the total abundance of any one sample not included. NMDS was used to graphically plot differences in species assemblages onto two dimensional charts in multidimensional space based on a Bray-Curtis similarity matrix, thus the axes have no scale. ANOSIM has been widely used for testing hypotheses about spatial differences and temporal changes in species assemblages (including fish) as well as for detecting environmental impacts (Chapman and Underwood 1999, Valesini et al. 2004). ANOSIM generates a value of R scaled between -1 and +1, with a value of zero representing no difference among a set of samples, and the closer the value to 1 the greater the biological importance of the differences. In ANOSIM, comparison of pair-wise R values, measuring how separate groups are on a scale of 0 (indistinguishable) to 1 (all similarities within groups are less than any similarity between groups) gives an interpretable number for the difference between groups. ANOSIM also gives a p-value (similar to an ANOVA, with values of $p < 0.05$ indicating significance). When differences were found using ANOSIM, then SIMPER analysis was used for identifying which species primarily account for observed differences in fish assemblages between paired restoration and reference sites. SIMPER generates a ranking of the percent contribution of the species that most contribute to the significant differences between factors.

Bioenergetics

We used a modified Wisconsin bioenergetics model (Hanson et al. 1997, Gray 2005) to estimate growth potential at restored and reference sites, and between hatchery and wild juvenile Chinook salmon. The parameters that we directly measured for input into the model included (1) water temperature, (2) energy density of representative prey items (verification of those taken from literature, see below), (3) instantaneous ration of food in collected juvenile Chinook salmon, and (4) consumption rate of juvenile Chinook salmon collected over a 24-hour period.

Temperatures were recorded at each site continuously every 15 minutes from 14 February 2005 to 21 July 2005 using Hobo sensors. Temperature files were adjusted for tidal dewatering so that only temperatures during submersion were retained. Daily average temperatures were calculated at each site (Appendix 1).

Accurate values for the energy density of prey items are required for the bioenergetics model. These values are determined through bomb calorimetry as calories per gram of dry weight (cal/g dw), and are then converted to joules per gram of wet weight (J/g ww) for input into the model using the dry weight-wet weight ratios determined before the bombing process. We used energy values from calorimetry of invertebrate taxa collected in the Salmon River estuary, Oregon, except for a few prey taxa for which these values were not available, in which case literature values were substituted (Table 1; Gray et al. 2005).

In order to validate the Salmon River prey energy values, we analyzed samples of four important Chinook prey items (*Corophium* spp., *Eogammarus* spp., Isopoda, and Polychaeta) collected at Turning Basin in May 2005. These taxa were sorted, weighed, and heat dried (55°C for 24-48 hours) until a stable weight was obtained. Pellets weighing between 0.0200-0.2000 g of dried material were burned in a Parr 1425 Semimicro Bomb Calorimeter according to standard procedures, and each resulting value (cal/g dw) was converted to kilojoules per gram of dry weight (kJ/g dw) and multiplied by the taxa-specific dry weight-to-wet weight ratio. The final values (kJ/g ww) of the four Turning Basin taxa were very similar to the values found by Gray et al. (2005) (Table 2), and the values from this publication for other taxa were used in our models.

Instantaneous ration is an indicator of feeding rate and is determined by dividing the weight of the stomach contents by the weight of the fish. The resulting value is between 1 and 0 with higher values indicating a faster feeding rate. We used values from representative juvenile Chinook salmon diet samples. Average instantaneous ration was compared among sites and between hatchery and wild salmonids using Kruskal-Wallis rank test which is the nonparametric alternative to ANOVA. The Kruskal-Wallis rank test was chosen because sample sizes were different.

Measuring consumption rate is generally difficult in estuarine environments and broad assumptions must be made. The fish are considered part of the same population, with all individuals feeding the same way (ignoring inherent immigration/emigration of salmonid populations). An attempt was made to estimate consumption rates more directly by sampling juvenile Chinook salmon every 3 hours with beach seines for a 24 hour period in order to determine the amount of food eaten per unit time. This sampling was conducted at the Turning Basin on 17 May 2005 and at Herring's House on 18 May 2005. Diets were collected with gastric lavage for up to 5 samples each of unmarked and marked Chinook salmon at each time interval. Unfortunately, the 24 hour sampling yielded atypically low diet contents in juvenile Chinook at most of the time points. This may have been due to extreme stormy, rainy weather that prevailed on the 24-hour sampling dates. Because of the minimal feeding, we used a standard consumption rate (see below).

Three different bioenergetics model runs were utilized, the first two on the enclosure net data, and the third on the beach seine data from the other component of the overall study:

1. A model using standard consumption of P = 0.5 (proportion of maximum consumption), determined from studies of other less industrialized estuaries on the Pacific Coast (Gray 2005). In this model observed differences are based on temperature and diets.
2. An identical model to (1), but with the P = 0.5 consumption rate adjusted, based on the instantaneous ration results (Fig. 28). The differences in ration were found to be significantly different among the sites (Kruskal-Wallis test, $p = 0.002$). The average Turning Basin ration was 0.017, compared to 0.005 at the other sites, or 71% greater at Turning Basin. The ration at the Salmon River in Oregon varied from 0.002 to 0.010 (Gray 2005), which is in the same range, indicating that the baseline conditions used in model 1 are reasonable.
3. One model run was conducted using the same parameters in (1) above, to test for differences in hatchery and wild fish captured around the Turning Basin area.

Results

Environmental Parameters

The Turning Basin and Hamm Creek sites had similar average salinities, ~1-2 parts per thousand (ppt) on the surface, and ~5-8 ppt on the bottom (Table 3). The Herring's House site was much more saline, with surface salinities averaging ~11 ppt on the surface and ~19-25 ppt on the bottom. Average water temperatures were quite consistent among the sites, ~11-12 ºC (Table 3, Appendix A). Average water depth at the net ranged from 1.4 m at the Herring's House restoration site to 2.9 m at the Herring's House reference site.

Overall Fish Catches

Composition

Twenty-three fish species were captured in the enclosure nets (Table 4). Five species made up the majority of the overall catch − shiner perch, chum salmon, threespine stickleback, staghorn sculpin (adults, and sculpin juveniles), and starry flounder. At the Turning Basin, percentages of overall fish catches were distributed into five main categories: shiner perch, sculpins, starry flounders, threespine sticklebacks, and juvenile chum salmon (Fig. 7). At the other two sites, catches were comprised of fewer dominant taxa. At Hamm Creek, shiner perch and juvenile chum salmon made up most of the total catch at the restored site, with juvenile chum salmon and sculpins dominating fish numbers at the reference site (Fig. 8). At Herring's House, shiner perch were very dominant at the restored site, and they were also relatively abundant at the reference site, along with sculpins and juvenile coho salmon (Fig. 9). Shiner perch increased in proportion from upstream to downstream sites, and threespine sticklebacks, starry flounders, and sculpins had the opposite pattern, increasing in proportion from downstream to upstream stations.

Abundance
Total fish catches were small in mid-February and mid-March, and increased in the April samplings to reach a peak in the May samplings (Fig. 10). There was another abundance peak on the last sampling date on 7 July. During both peak periods, shiner perch comprised the majority of the fish catch (mostly juveniles on the 7 July sampling date). On the 29 March and 12 April sampling dates, juvenile chum salmon dominated the overall fish numbers. Juvenile salmonids occurred on every sampling date (Fig. 11). Chum salmon were the most abundant salmonid species from late March through early May sampling dates, reaching peak densities on the 12 April sampling date. Unmarked Chinook fry occurred in early February and March peaking on 15 March, and most Chinook smolts appeared in April, with a peak abundance of both unmarked and marked Chinook smolts on the 7 June sampling date. Coho salmon were relatively abundant only on the 26 April sampling date, when they were represented almost entirely by marked hatchery fish. Sockeye, pink salmon, steelhead trout, and cutthroat trout occurred only in low numbers (15 total fish).

<u>Fish Catches at Paired Restored/Reference Sites</u>
At the Turning Basin, fish taxa richness was higher at the restored site than at the reference site (13 vs. 8 species) (Table 5). There was a large peak in total fish density (>4,000/acre) at the reference site on the 10 May sampling date, mostly comprised of chum salmon and sculpins (Fig. 12). On two other dates, 24 May and 23 June, densities at the reference site were more than twice those at the restoration site, and on 29 March densities at the restoration site were more than twice those at the reference site (but lower overall densities <500/acre). On other sampling dates, densities were similar at the two sites, and based on ANOVA results, overall fish densities were not significantly different. In contrast to combined fish results, juvenile Chinook salmon were more abundant at the Turning Basin restored site on all sampling dates except 10 May and 6 July, and overall Chinook salmon densities were significantly higher at the restored site (ANOVA, $p < 0.01$; Table 6; Fig. 13). Unmarked fry dominated Chinook composition February-March, and marked hatchery Chinook smolts dominated April-June. Juvenile coho salmon occurred in relatively high density only on the 10 May sampling date at the Turning Basin restoration site (Fig. 14). During their period of peak abundance, March-May, chum salmon relative abundances varied considerably among and between sites and dates (Fig. 15). On two sampling dates (29 March, 26 April) abundances were higher at the restoration site, and on two dates (12 April, 10 May) they were higher at the reference site. On other sampling dates, chum salmon occurred only at the restoration site in relatively low numbers.

Due to logistical problems, the enclosure net was not deployed at the Hamm Creek reference site on the 16 March and 25 May sampling dates. At this site, the difference in fish taxa richness between the restored and reference site was similar to that at the Turning Basin site (15 vs. 10 species, respectively; Table 5). At Hamm Creek there were two large peaks in fish densities at the reference site, on 12 April, when composition was dominated by chum salmon, and on 10 May, when sculpins dominated (Fig. 16). Total fish were usually more abundant at the reference site, however densities at the restoration site were higher on 26 April, 7 June, and 6 July. ANOVA indicated that the overall difference between the restored and reference sites was not statistically significant (Table 6). On two sampling dates (10 May and 7 June), juvenile Chinook salmon were relatively abundant at the Hamm Creek site (Fig. 17). On the first of these dates, they consisted of both unmarked and marked hatchery fish and occurred only at the reference site; on the latter date they were present in similar numbers at both the restoration and reference sites, and consisted mainly of marked hatchery fish. As at the Turning Basin site, juvenile coho salmon were present in relatively high density only on the 10 May sampling date (Fig. 18). On this date, they were dominated by unmarked fish, and occurred only at the reference site. Juvenile chum salmon captured at Hamm Creek reached peak abundance on the 12 April sampling date (Fig. 19). Chum were most abundant at the reference site on three of the five sampling dates on which they were present.

Fish taxa richness at Herring's House was identical at the two sites (13 species at the restored site, 13 species at the reference site; Table 5). Overall fish densities at Herring's House peaked on the 26 April sampling date, mainly due to a large coho salmon catch at the reference site (Fig. 20). Relative abundance of shiner perch was much higher at Herring's House as compared to the other two locations, dominating the catches on the May sampling dates at both the restoration and reference sites, and at the restoration site on several other sampling dates. Several fish species (e.g., gunnels) occurred at Herring's House but not at the two upstream sites. Total fish densities were higher at the reference site on almost every sampling date, but ANOVA indicated that this difference was not statistically significant ($p = 0.068$; Table 6). Juvenile Chinook salmon were relatively abundant only on the 24 May and 7 June sampling dates, when they were dominated by marked hatchery fish (Fig. 21). On these two dates, Chinook densities were much higher at the reference site compared to the restoration site, but based on ANOVA, overall densities were not significantly different between the two sites (Table 6). At Herring's House, coho salmon appeared in high density only on the 26 April sampling date, and only at the reference site (Fig. 22). Almost all coho found at Herring's House were marked hatchery fish. Relatively high abundances of juvenile chum salmon occurred at Herring's House on the 26 April, 10 May, and 7 June sampling dates (Fig. 23). On these dates abundances were higher at the reference site, while on other dates of lesser abundances chum densities were higher at the restoration site.

Multivariate analysis of the fish community based on density estimates proved to be a "useful" model according to statistical guidelines (stress less than 0.2 considered useful; Clarke 1993), showing a MDS ordination 2-d stress of 0.19 (Figs. 24, 25). The ordination plots show that fish densities cluster more tightly based on time (Fig. 25) than based on site (Fig. 24). Analyzing the log-transformed fish density data using a 2-way ANOSIM (site x week) also showed that week is a more important factor than site in the analysis (R-value 0.417 vs. 0.151; the higher the R-value the greater the biological importance), although both were significant ($p < 0.01$; Table 7). One-way ANOSIMs were used to show the degree to which the restored and reference differed at each site pair. This analysis showed that the reference and restored sites were significantly different at Turning Basin and Herring's House, but not at Hamm Creek (Table 7). R-values again were of moderate biological importance, being greatest at Herring's House and Turning Basin (0.223 and 0.118 respectively; Table 7). SIMPER analysis showed that the main species driving the significant differences were high densities of 1) starry flounder and sculpin at Turning Basin reference sites, 2) chum and Chinook salmon at Turning Basin restored site, 3) sculpins at the Herring's House reference site, and 4) shiner perch at the Herring's House restored site (Table 7).

Juvenile Chinook Salmon Diets

Due to low Chinook numbers at the Turning Basin reference enclosure net site, diet analysis of Chinook collected from the Turning Basin beach seine site from the other component of the study was substituted as a reference for this pair. Diets based on 19 prey categories were similar between the restored and reference sites most dates (Fig. 26A-E). Exceptions to this were: (1) in March at Herring's House, where the restored site had more chironomids, diptera larva, and annelid worms (OligoPoly), and the reference site had more *Corophium* spp. amphipods and "other" category (Fig. 26A); (2) in June at Hamm creek, where the restored site had more chironomids and dipteran larva and the reference site had more Homoptera, Hymenoptera, and Lepidoptera (Fig. 26C); and (3) in May and June at the Turning Basin, where restored site had more annelids and the reference site had more *Corophium* spp. and chironomids (Fig 26C,D). Prey was usually distributed into a number of categories, except at the Turning Basin in April, when annelids were largely dominant at both the reference and restored site (Fig. 26B). When both hatchery and wild juvenile Chinook salmon were relatively abundant in May and June, diets from the beach seine sampling were quite similar between the two groups (Fig. 27).

Bioenergetics Models

On all sampling dates, average instantaneous ration (g stomach contents/g fish) of juvenile Chinook salmon was highest at the Turning Basin (Fig. 28; Kruskal-Wallis test, $p = 0.002$). At the other two paired sites, instantaneous ration was lower, except at Herring's House in March, when values were similar to those at the Turning Basin, and higher than those at Hamm Creek. Instantaneous ration was similar between hatchery and wild juvenile Chinook salmon captured in beach seines in the Turning Basin area (Fig. 29).

The results of the three different bioenergetics models that we conducted were as follows:

1. With standard consumption set at $P = 0.5$ (model results based on temperature and diets), modeled growth was less in March and April, and greater in May and June (Fig. 30). In most months, modeled growth was similar at the restored and reference sites at each enclosure net location. Exceptions were higher modeled growth at the Herring's House restored site in May and at the Hamm Creek reference site in June (Fig. 30).
2. With consumption rate adjusted by instantaneous ration, modeled growth was higher at the Turning Basin sites (Fig. 31).
3. For beach seine-caught wild and hatchery juvenile Chinook from the Turning Basin area, modeled growth was highest in February and June, respectively (Fig. 32). When wild and hatchery fish co-occurred, modeled growth was similar in April and May, but hatchery Chinook had greater modeled growth than wild Chinook in June.

The 24-hour sampling at Turning Basin (17 May) and Herring's House (18 May) was problematic for determining adjusted consumption rates, due to harsh weather conditions with heavy rain. Such measurements were time-intensive and difficult to make, and point to the necessity of a determined effort with multiple 24-hour samplings if the data is to be representative of the overall field sampling effort. Consumption rates calculated during this time period were very low ($P = 0.064$ at Herring's House, $P = 0.044$ at Turning Basin). Using this data, the bioenergetics model was problematic, illustrating negative growth rates, with increasing temperatures for each month leading to further decreased growth.

Summary and Discussion

Overall Fish Assemblages and Abundances

The results of our study suggest that one important factor structuring fish assemblages at the sampled sites is salinity. The more marine-influenced site (Herring's House) was largely dominated by shiner perch, and had some marine fish not found at other sites, while the two lower salinity sites had more starry flounder, sticklebacks, and sculpins. We note, however, that high densities of some of these species can occur at any of the sites on a given date. For example, high shiner perch numbers were found at the Turning Basin on several occasions and sculpins were sometimes relatively abundant at Herring's House. This lack of consistent site fidelity is corroborated by MDS analysis, which found that time is a more important fish assemblage structuring factor than site. Two examples of the strong time component in fish assemblage structure are chum salmon, which were most abundant March-April, and shiner perch, which were most abundant May-June. One important unresolved question is the degree to which abundant non-salmonid species compete with juvenile salmon using Duwamish estuary habitats. In several cases, high densities of non-salmonids overlapped with relatively high densities of juvenile salmon (e.g., sculpins and chum salmon at the Turning Basin reference site on 10 May, sculpins, shiner perch, and Chinook salmon on 7 June at the Herring's House reference site). Conducting diet studies of fish that co-occur with juvenile salmon would help to understand how much their diets overlap with the salmon and allow estimates of competition between the species that are abundant in the Duwamish estuary.

Overall fish taxa richness was higher at the restored site at Turning Basin and Hamm Creek, while at Herring's House the restored and reference sites had identical taxa richness values. Fish assemblages were also different between two of the paired restoration and reference sites, as found by ANOSIM analysis at Turning Basin and Herring's House, but this was not the case at Hamm Creek. This suggests that, although parametric statistics did not find significant differences in overall fish densities among sites and times, alternative metrics of fish community structure indicate that restored sites may harbor different and perhaps more diverse fish assemblages. In this study, we only measured fish at mid- to high tidal elevations, because the restoration sites almost completely dewater at lower tides. However, restoration of lower elevation habitats (e.g., mudflats) may also provide both prey (e.g. benthic amphipods) and extended refuge benefits (i.e., more time spent at restored habitat), and future restoration projects should consider extending into lower elevations.

Juvenile Salmon Assemblages and Abundances

Our data showed a pattern of juvenile salmon occurrence similar to previous findings from the Duwamish River, with chum salmon and wild Chinook peaking March-April and hatchery Chinook and coho peaking later. Coho salmon were relatively rare in our samples and were dominated by hatchery fish.

The only statistically significant difference we found for juvenile salmon among paired restored and reference sites was for Chinook salmon at the Turning Basin. At this site Chinook were consistently more abundant at the restoration site. We do not know the underlying reasons for this, but several factors may be important. First, fish access to the Turning Basin restored site is greater than for the other two restored sites at Hamm Creek and Herrings House. This site consists of an off-channel basin with mudflats and an unobstructed opening to the main channel of the Duwamish estuary, whereas the other two sites have relatively small openings through which fish must enter the restored habitat areas. Second, juvenile Chinook salmon densities and residence may be greater in the Turning Basin area than in other parts of the estuary (Nelson et al. 2004), and if restored site relative use is density dependent, the fish would be more likely to occur at the restoration site there than at the other two sites. This increased density and residence at the Turning basin may occur because it is located in a less industrialized landscape at the upstream terminus of the dredged waterway. The habitat there may be more attractive to juvenile salmon than at Herring's House, where the waterway is heavily industrialized, has much more boat traffic, and is more saline.

Juvenile Chinook Salmon Diets and Bioenergetics

Juvenile Chinook salmon in this study fed on a variety of benthic invertebrates, terrestrial insects, and emergent marsh insects, similar to results from previous diet studies in the Duwamish estuary (Cordell et al. 1999). Perhaps the most striking result is the consistently higher instantaneous ration obtained by the fish at both the restored and reference Turning Basin sites. This higher ration also translated into higher modeled growth rates at the Turning Basin as compared to the other locations, when the model consumption rate was adjusted for instantaneous ration. These findings could be the result of 1) more intensive fish foraging there, 2) better prey availability in the area, and 3) more active rearing as opposed to farther downstream sites such at Herrings House, where they are probably more migratory. Regardless of the reasons, our results suggest that the benefits to juvenile Chinook salmon of locating future intertidal habitat restoration projects near the Turning Basin may be high. However, this does not mean that other sites in the estuary should not be restored. Recent studies in the Duwamish Waterway have indicated that restored sites in more industrialized sections of the waterway also provide access and biological function for juvenile salmon (Cordell et al. 1999). Also, the Turning Basin area has a cluster of four restoration sites that may enhance its benefit for salmon relative to downstream individual sites, and the more industrialized sections of the waterway may also benefit from similar site clustering in the future. One important factor in restoring function for juvenile salmon in the Duwamish waterway is establishing sites that enhance connected linkages between restored sites. Currently, there is a gap of several miles between the cluster of restored sites at the Turning Basin and those downstream.

The bioenergetics models did not verify our hypothesis that restored sites provided juvenile Chinook salmon with enhanced growth potential: modeled growth rates were similar among the restored and reference sites or were inconsistent among sites and months (i.e., higher at the reference site one month and at the restoration site in another month, at a given site). One explanation for this is that prey is not limiting for juvenile Chinook salmon in the lower Duwamish River, and that they acquire adequate food throughout the waterway. This is corroborated by the fact that our modeled growth rates were quite similar to those found in the Salmon River, a more natural estuary on the Oregon coast (Gray 2005). Another possibility is that our models lacked the precision needed to detect differences in growth potential between the sites. We were unable to adequately measure in situ consumption because of the scarcity of prey in our 24-hour sampling, and used consumption rates based on data from other estuaries.

Successful measurement of real consumption rates may help increase precision in future applications of this technique to restored sites. Also, fish retained by the enclosure nets were only feeding at a given site for a maximum of several hours, before the site dewatered. Prey obtained before enclosing the fish may still have remained in their stomachs, which could have further reduced precision of the model. This problem could be alleviated by enclosing restored sites before inundation and then introducing starved fish, so all prey obtained was from the enclosed site.

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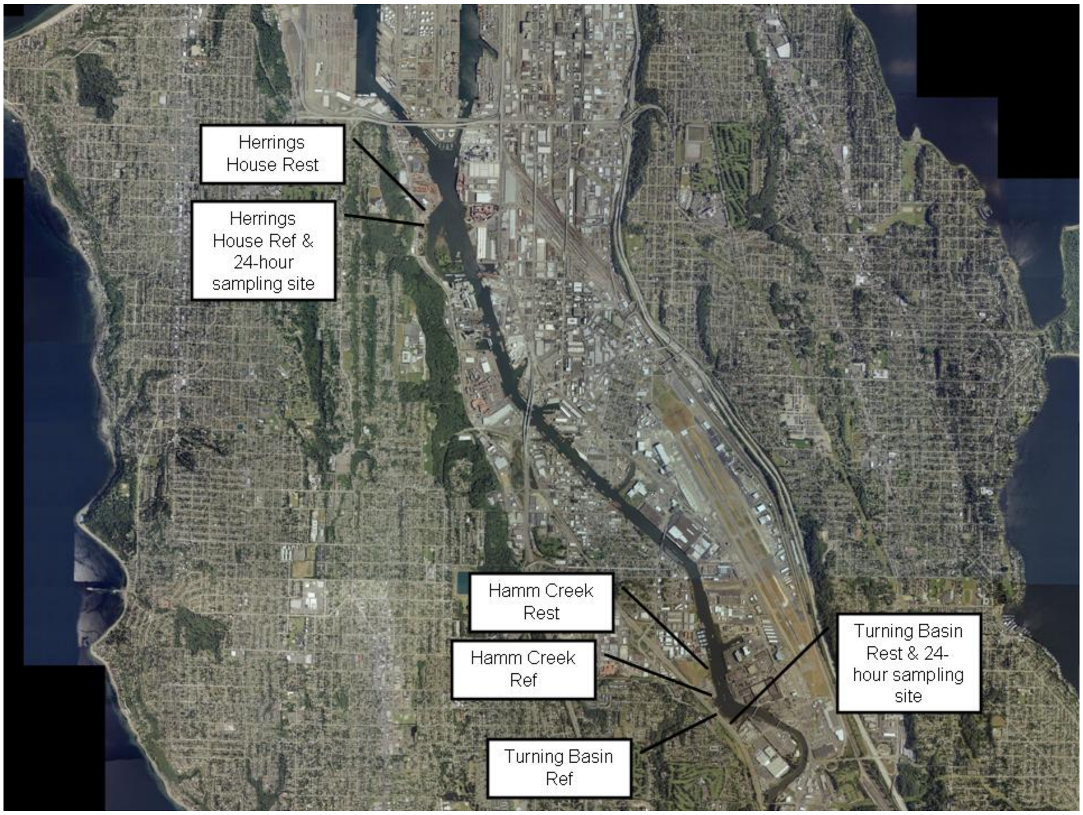


Figure 1. Map of Study sites.


Figure 2. Deploying the enclosure net at Turning Basin.


Figure 3. Pole-seining within the enclosure net at Turning Basin.


Figure 4. Captured juvenile salmonids.

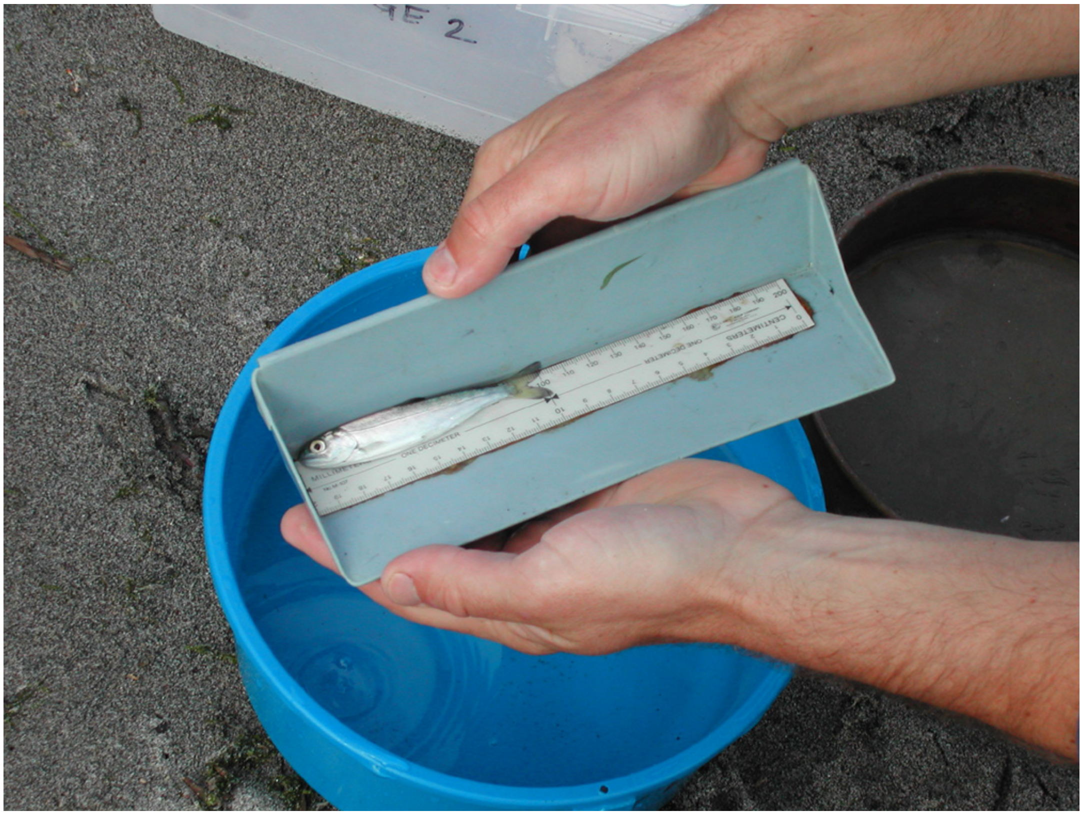


Figure 5. Measuring forklength of a juvenile salmonid.

Figure 6. Sampling fish-diets with gastric lavage.

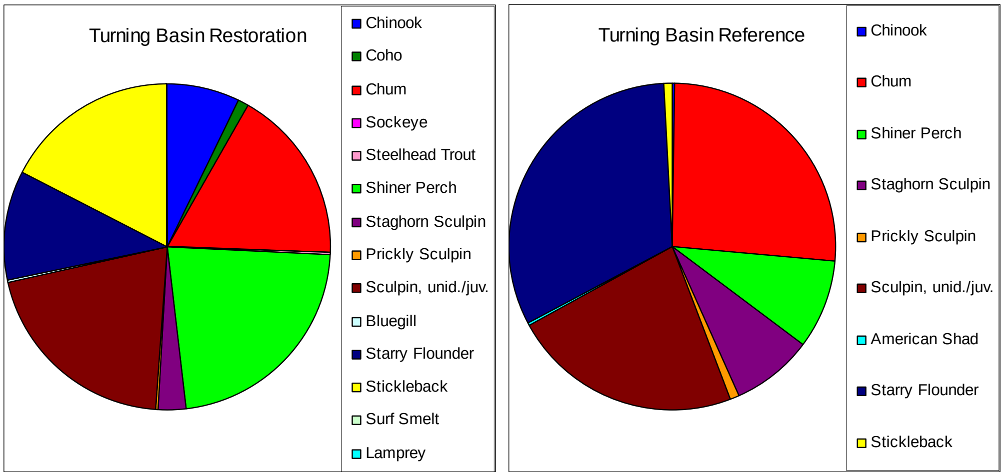


Figure 7. Percent composition of total fish catches at Turning Basin restoration and reference sites, all fish species represented, rare species may not be visible as a wedge.

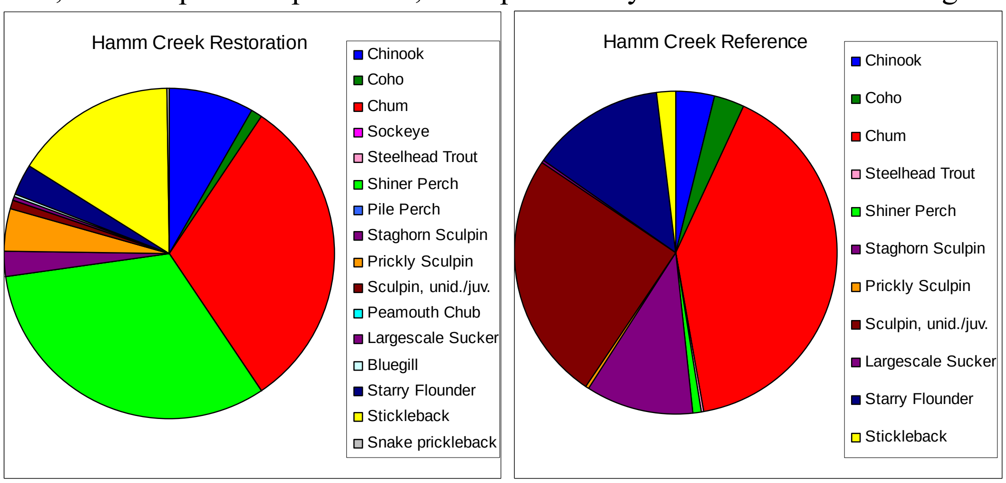


Figure 8. Percent composition of total fish catches at Hamm Creek restoration and reference sites, all fish species represented, rare species may not be visible as a wedge.

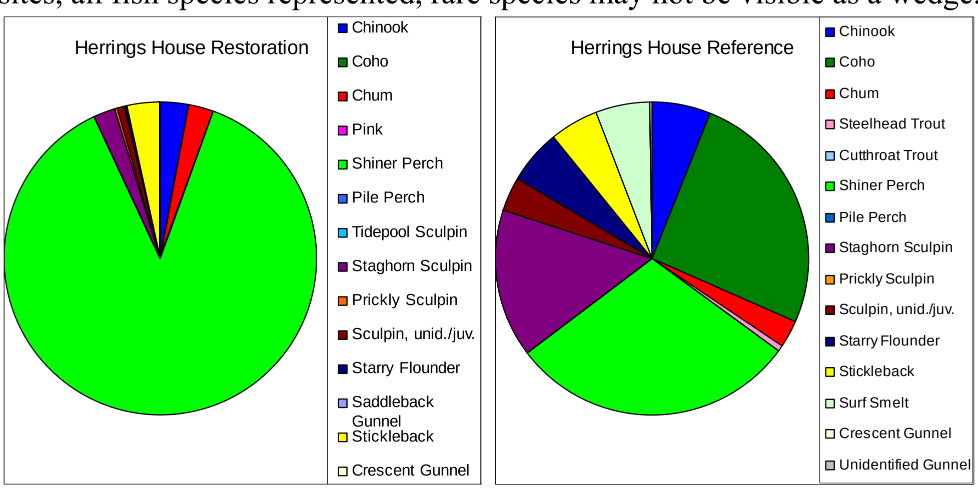


Figure 9. Percent composition of total fish catches at Herring's House restoration and reference sites, all fish species represented, rare species may not be visible as a wedge.

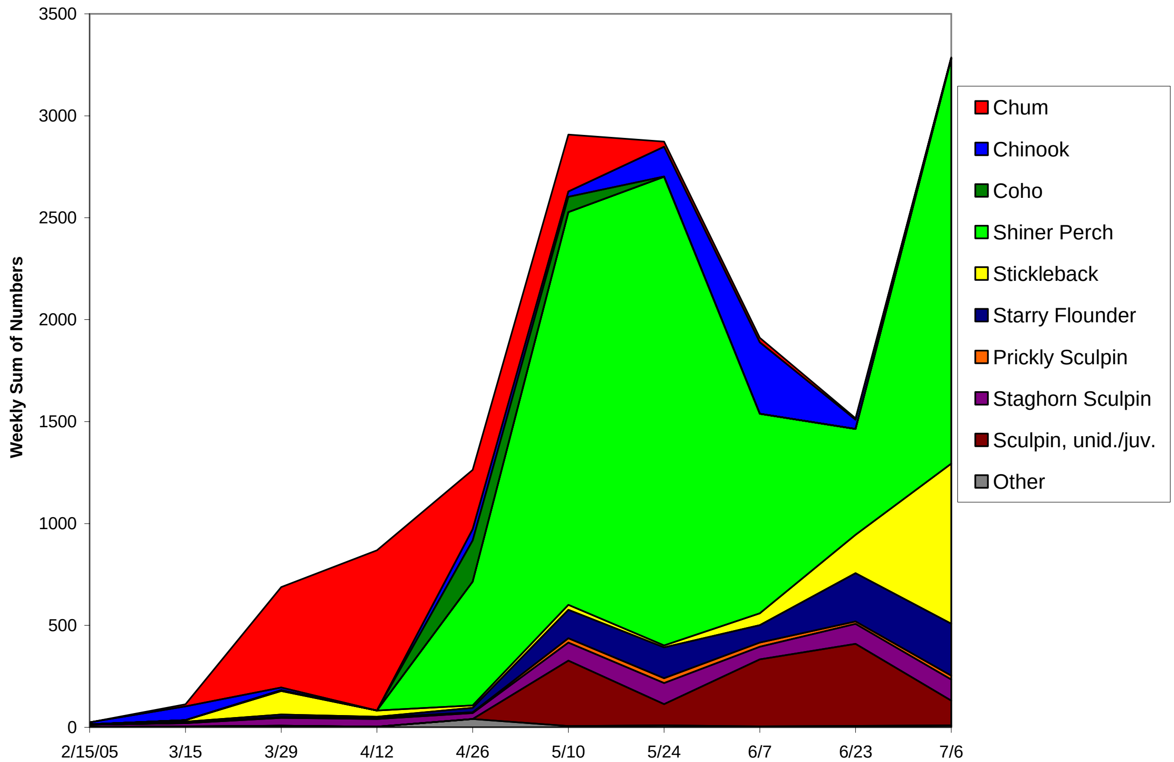


Figure 10. Sampled fish during each week, summed over all sampling sites.

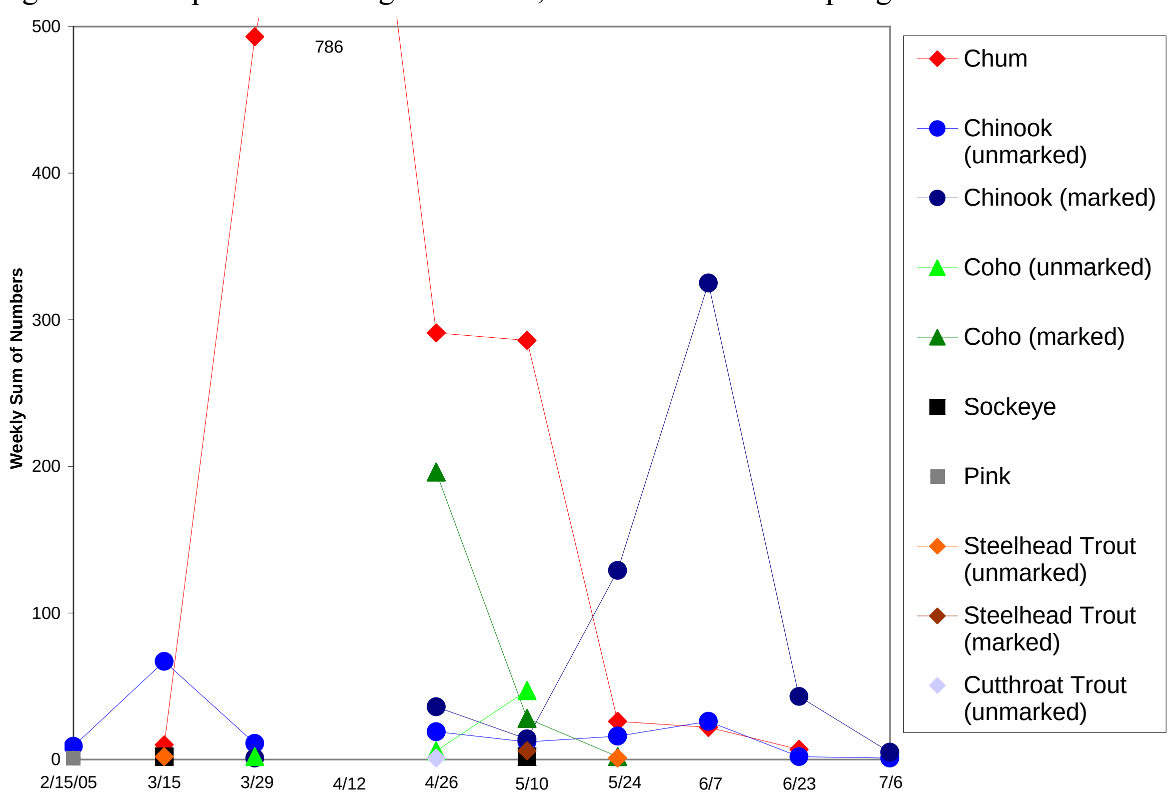


Figure 11. Sampled juvenile salmonids during each week, summed over all sampling sites.

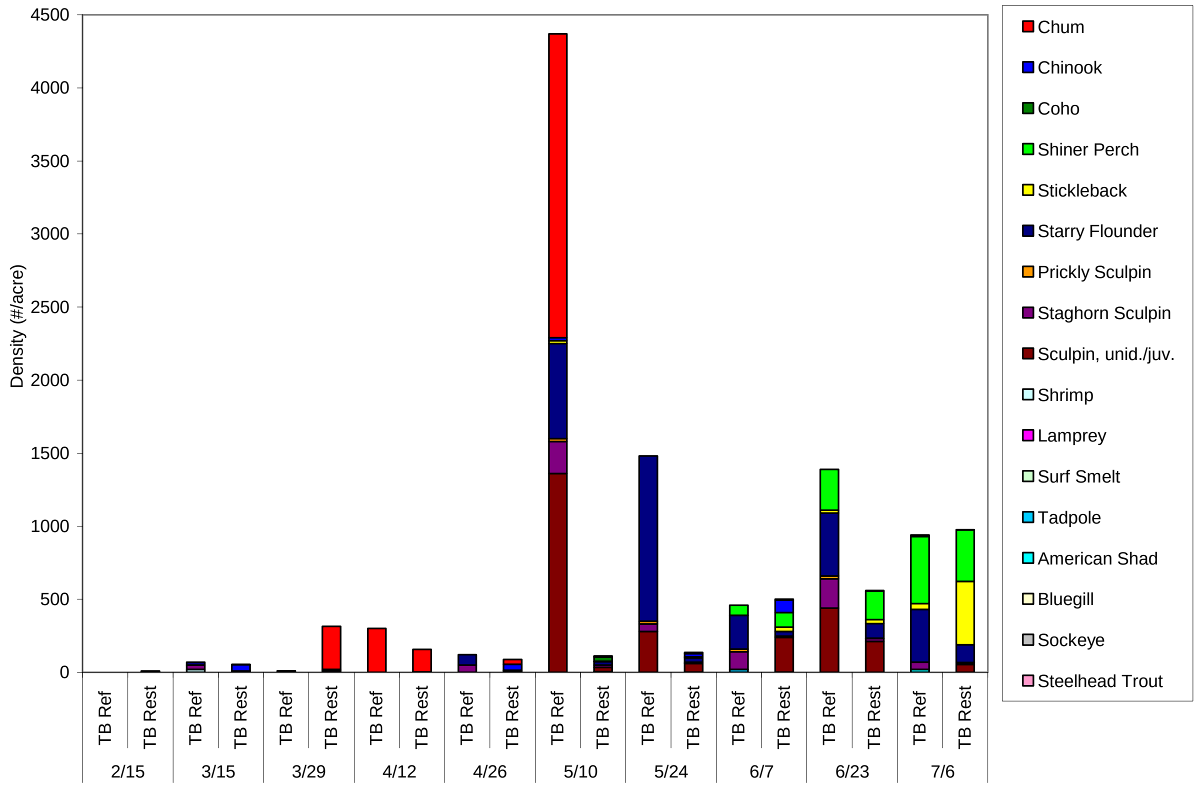


Figure 12. Fish abundances at Turning Basin restored and reference.

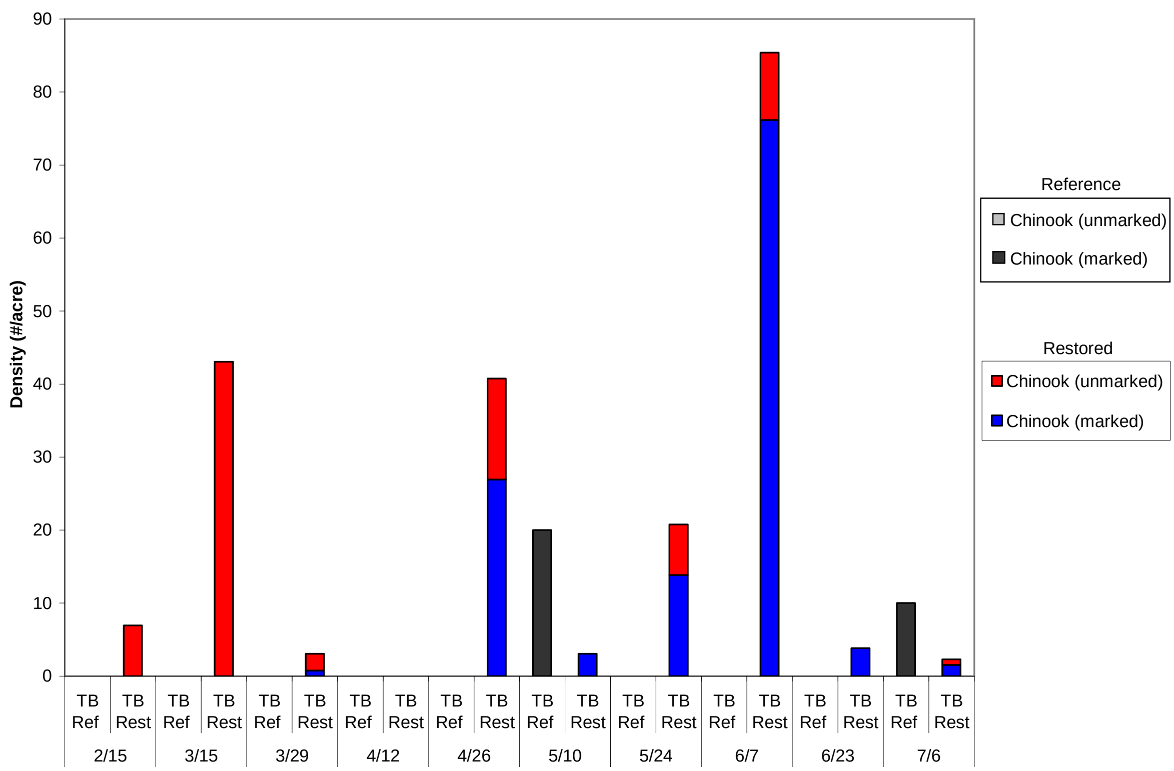


Figure 13. Chinook abundances at Turning Basin restored and reference.

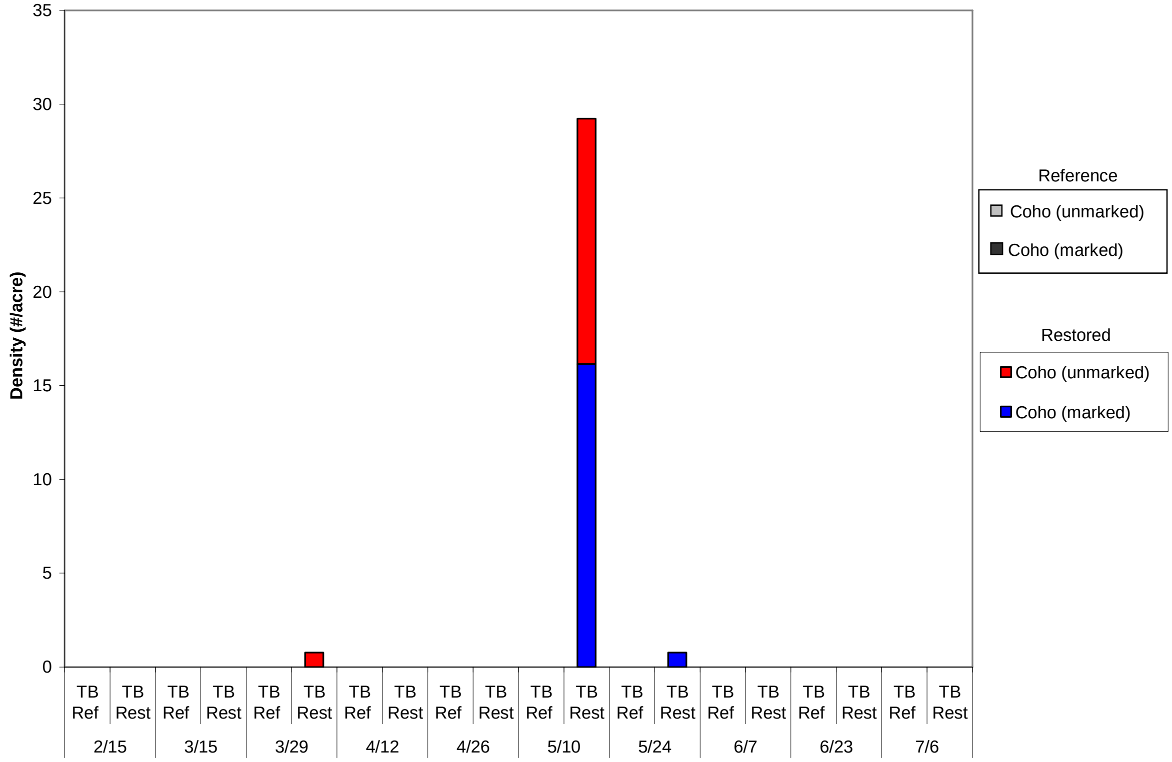


Figure 14. Coho abundances at Turning Basin restored and reference.

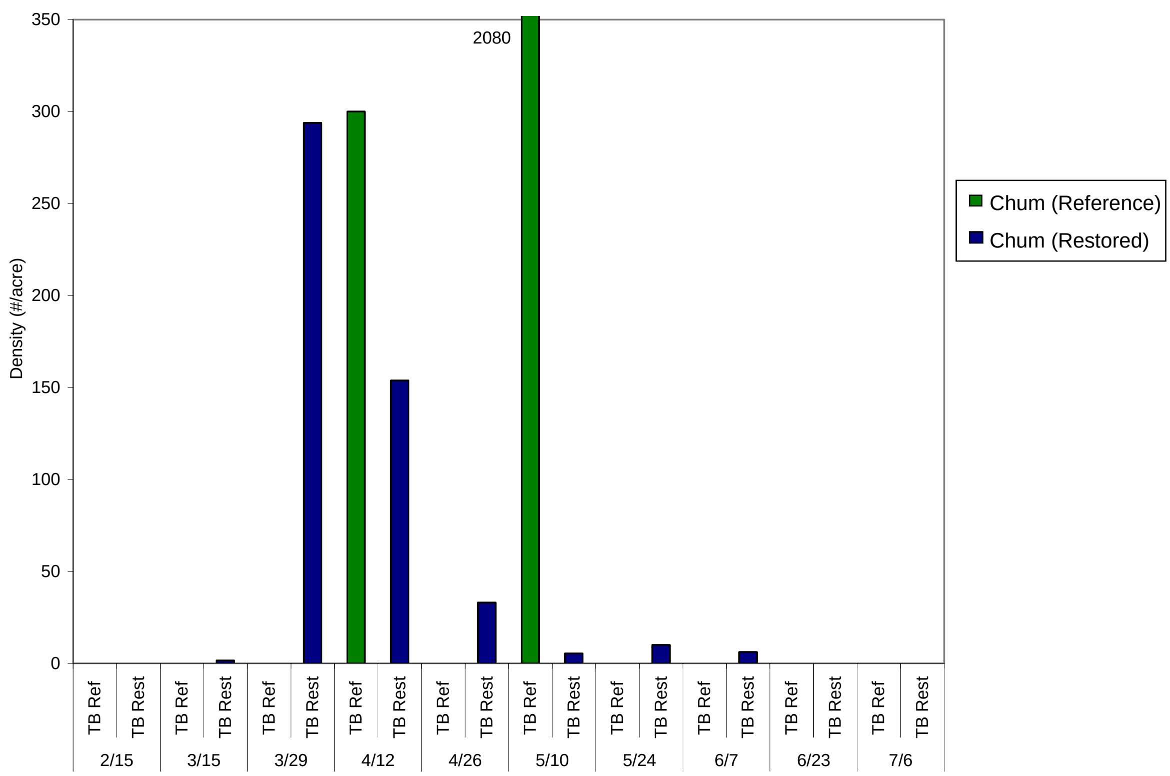


Figure 15. Chum abundances at Turning Basin restored and reference.

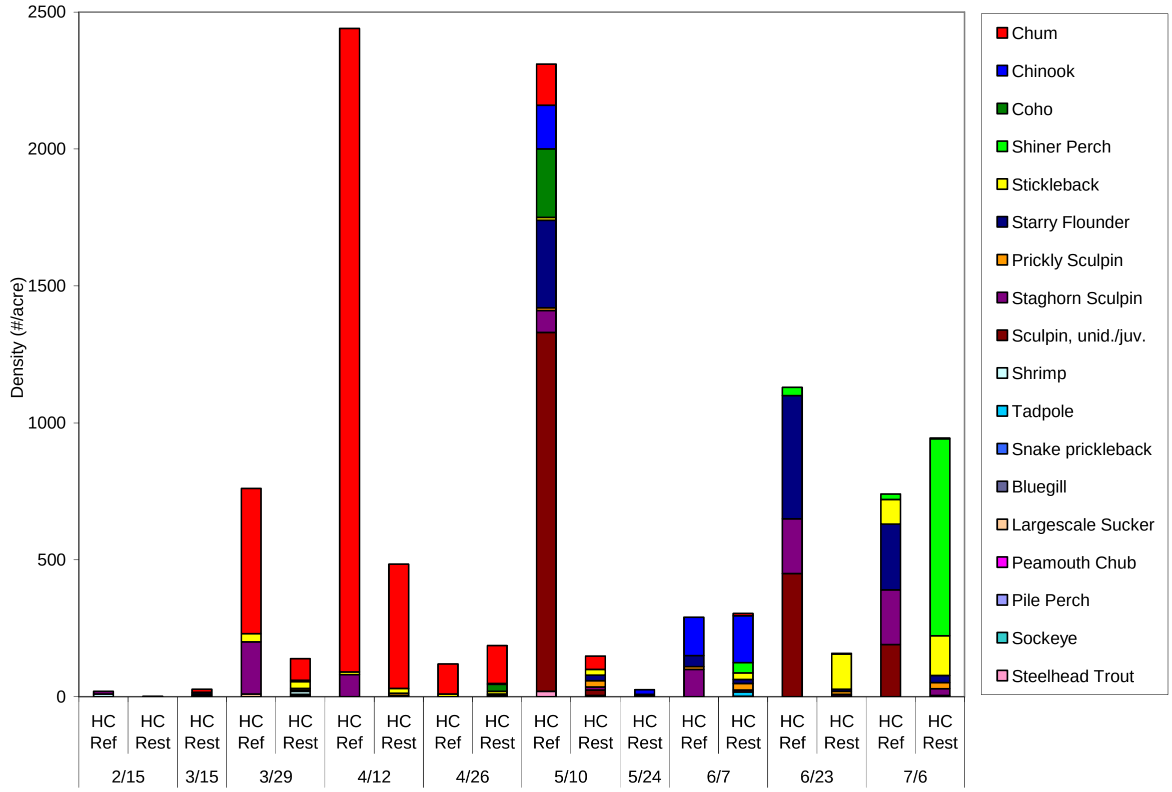


Figure 16. Fish abundances at Hamm Creek restored and reference.

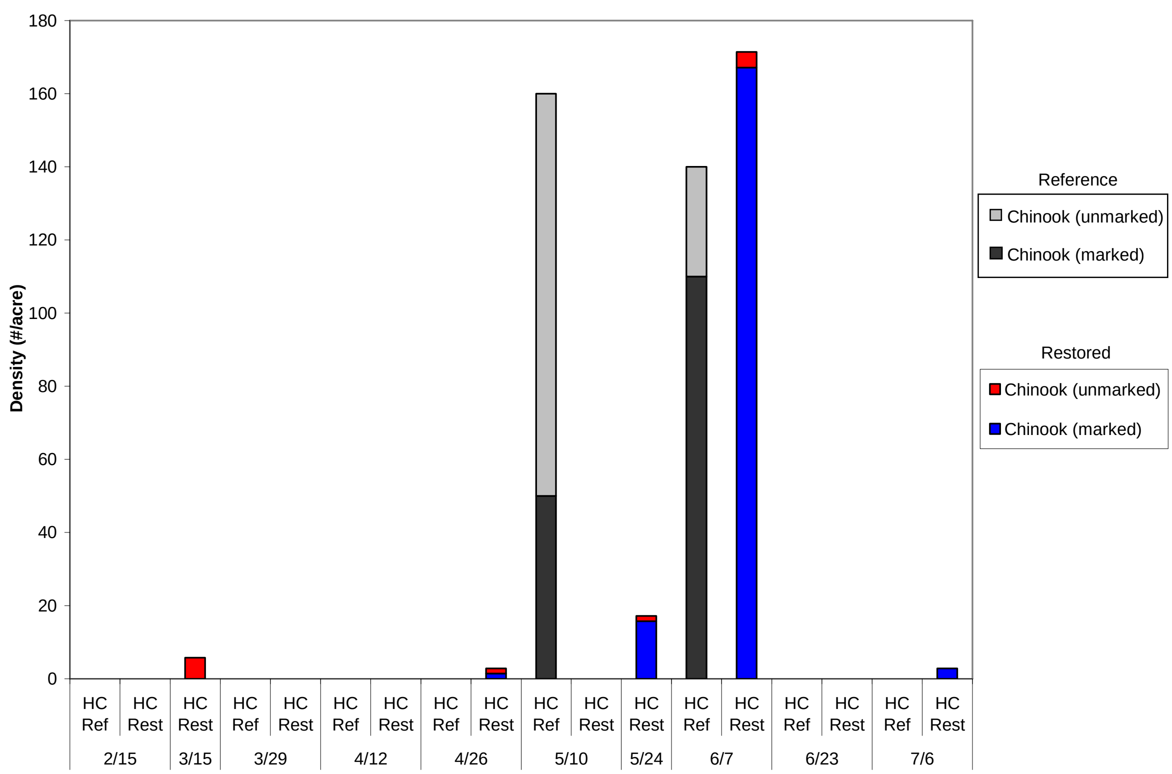


Figure 17. Chinook abundances at Hamm Creek restored and reference.

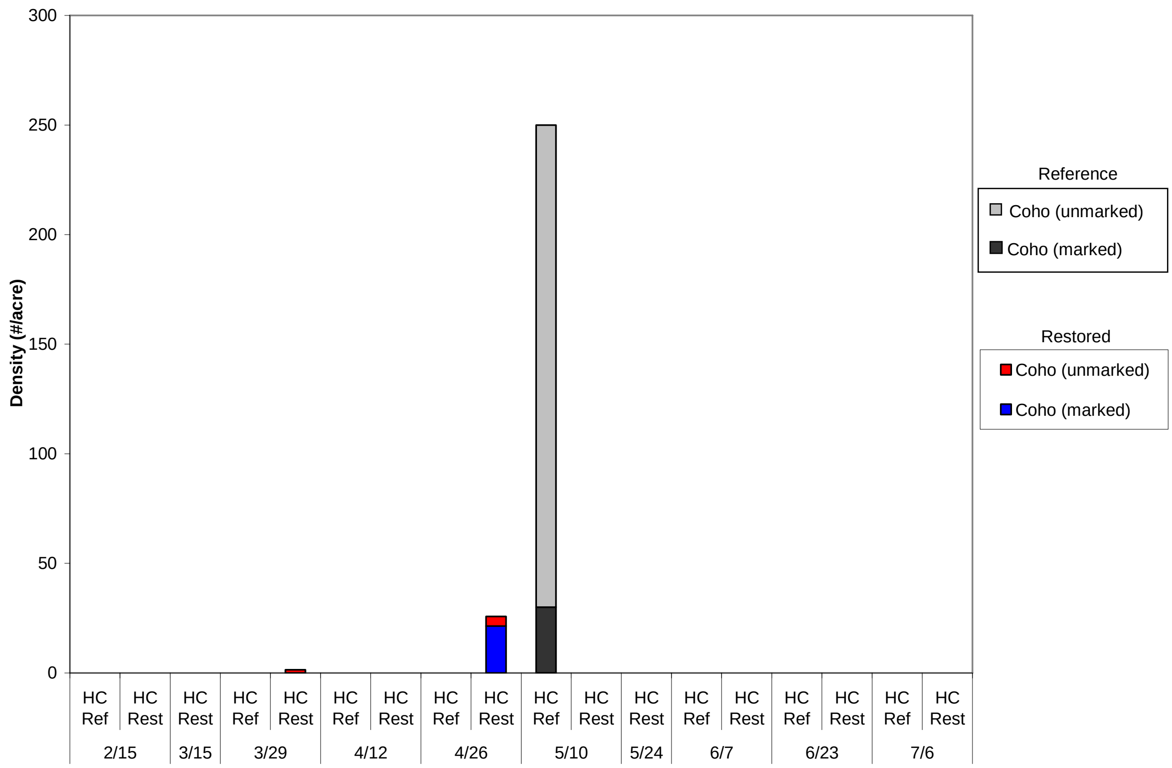


Figure 18. Coho abundances at Hamm Creek restored and reference.

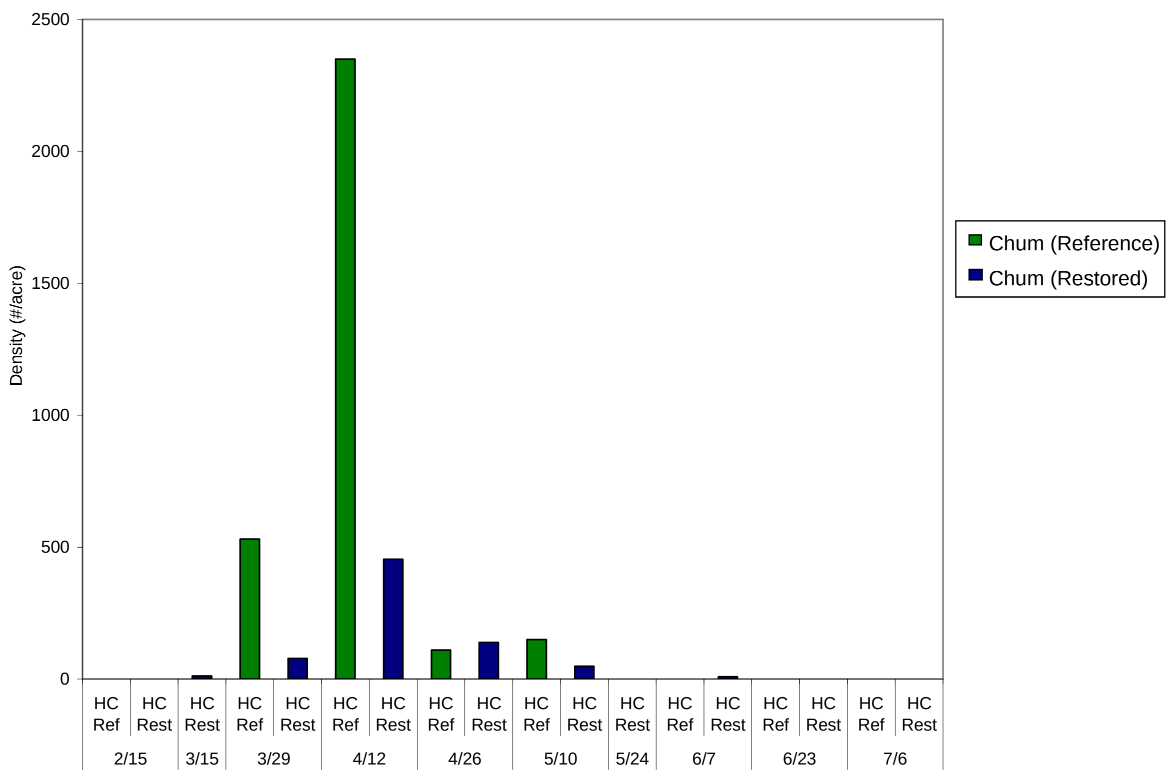


Figure 19. Chum abundances at Hamm Creek restored and reference.

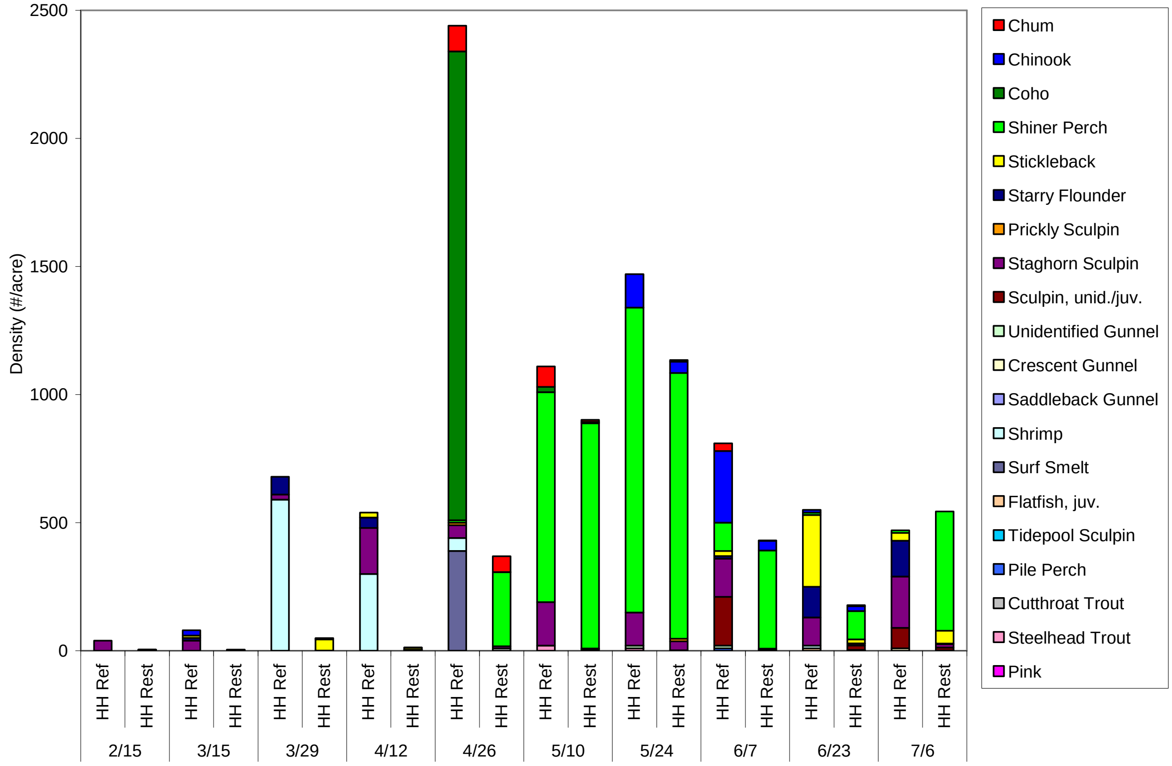


Figure 20. Fish abundances at Herrings House restored and reference.

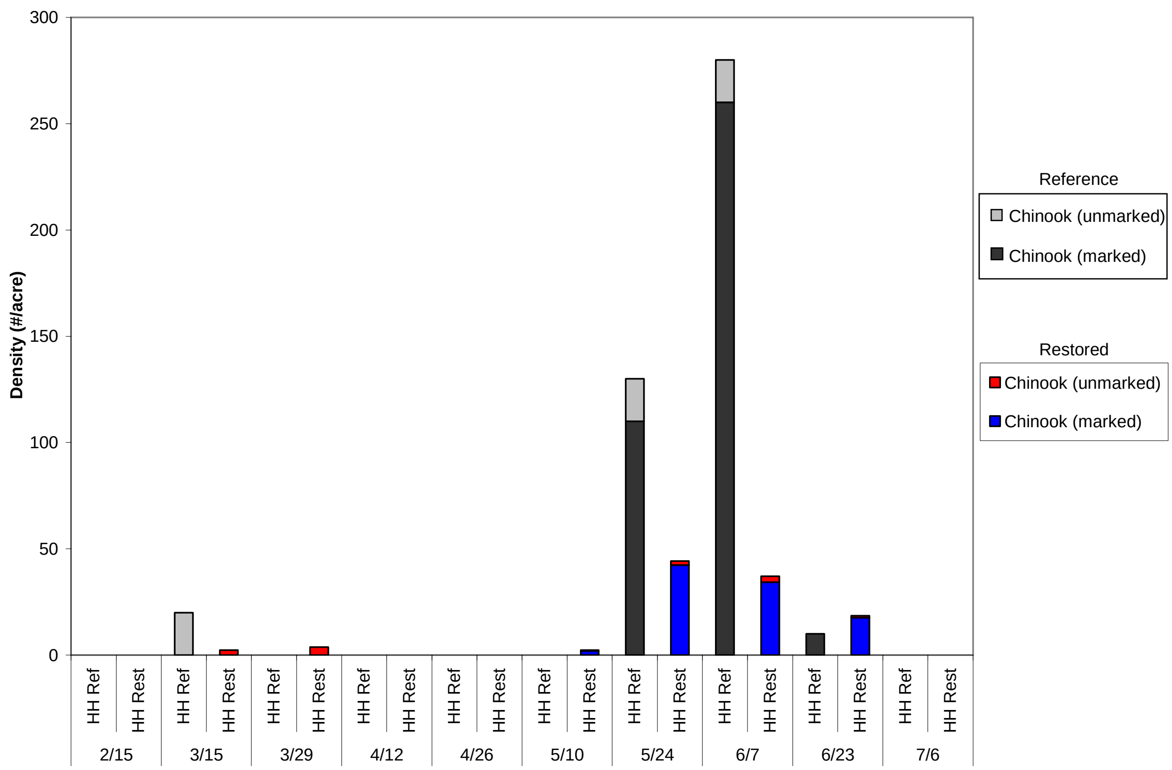


Figure 21. Chinook abundances at Herrings House restored and reference.

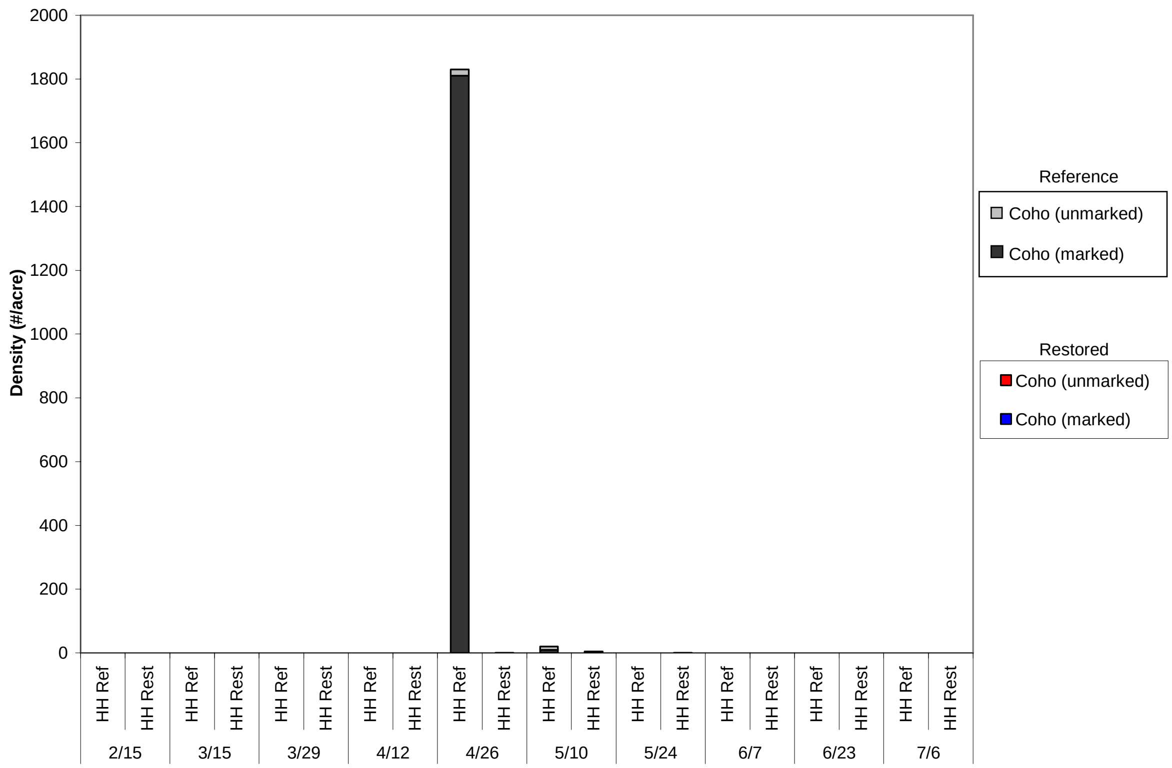


Figure 22. Coho abundances at Herrings House restored and reference.

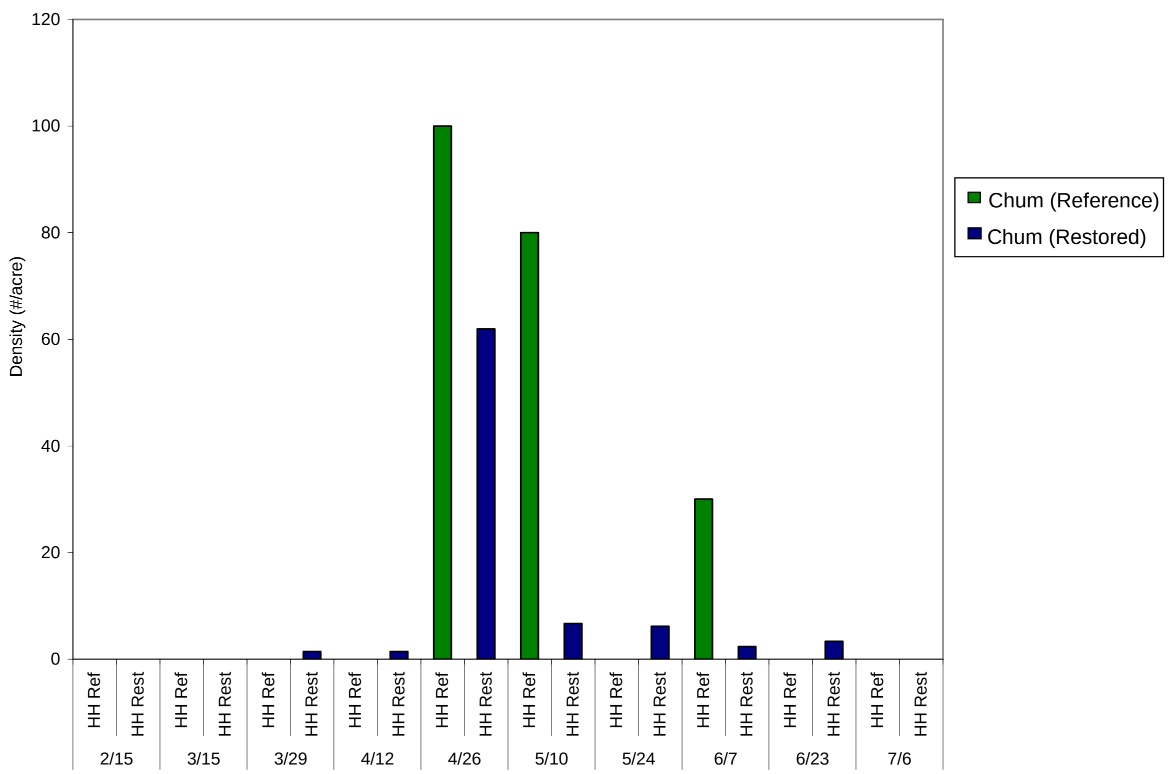


Figure 23. Chum abundances at Herrings House restored and reference.

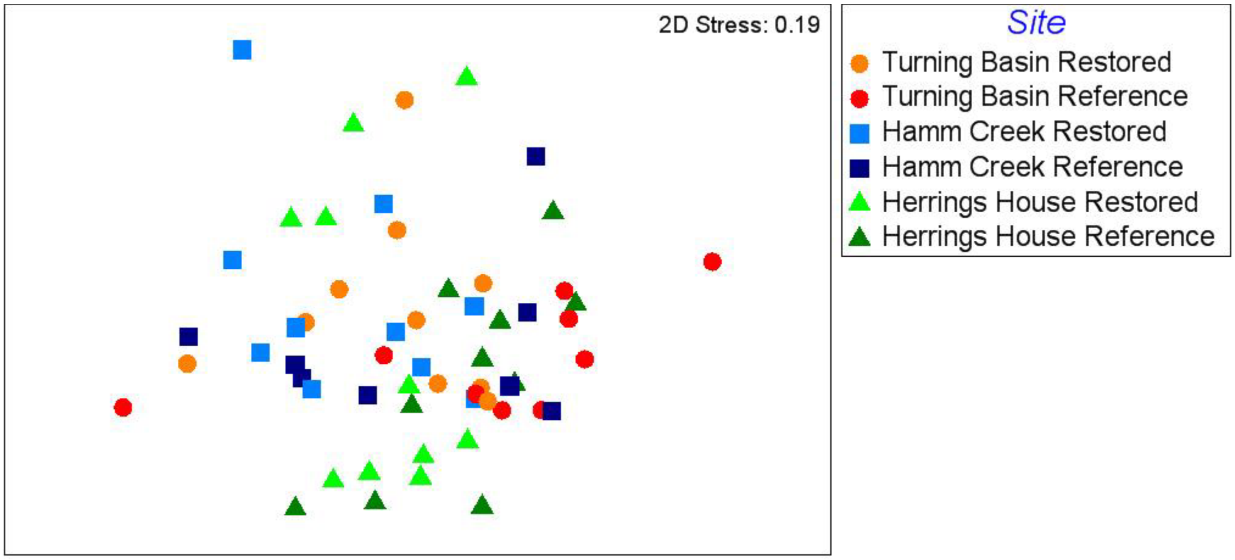


Figure 24. MDS ordination on fish densities, plotted for each site.

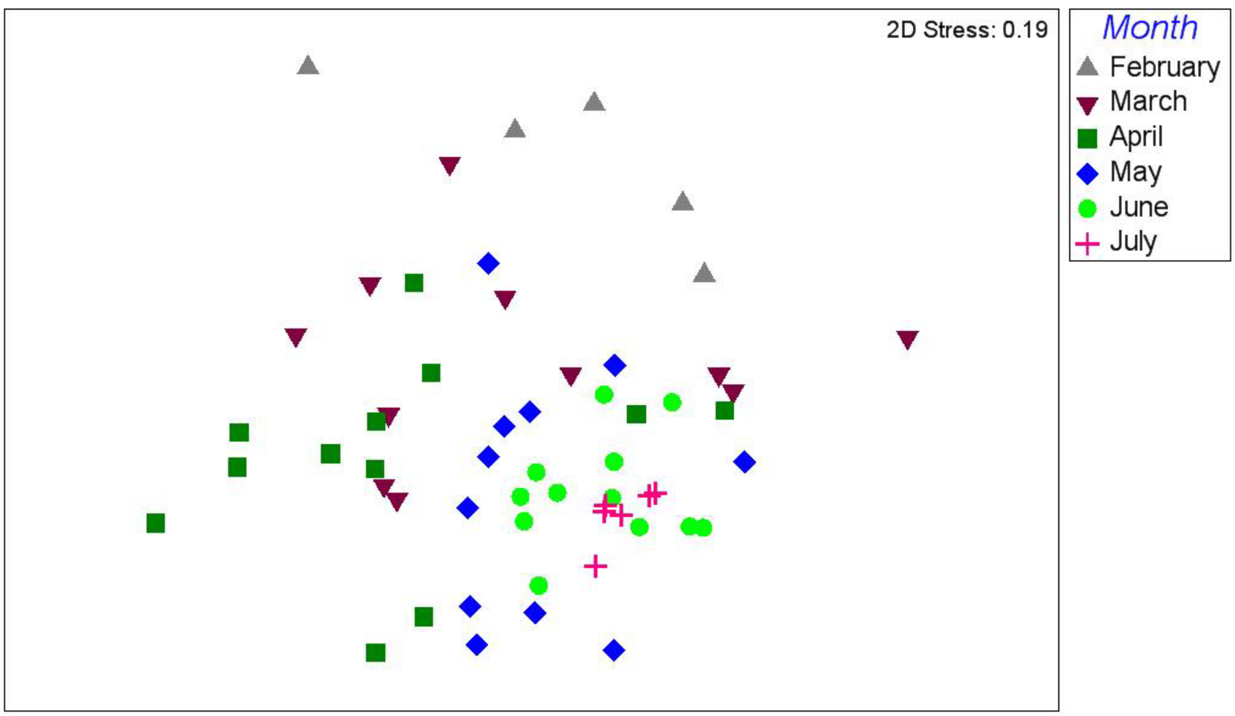
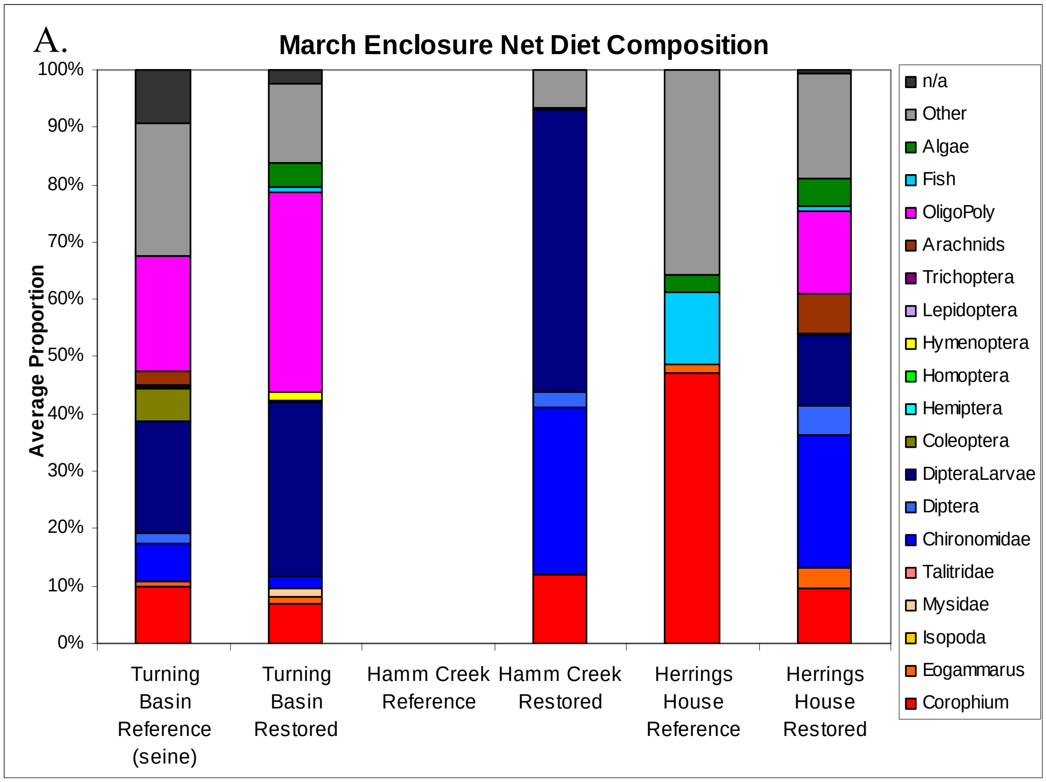


Figure 25. MDS ordination on fish densities, plotted for each month.



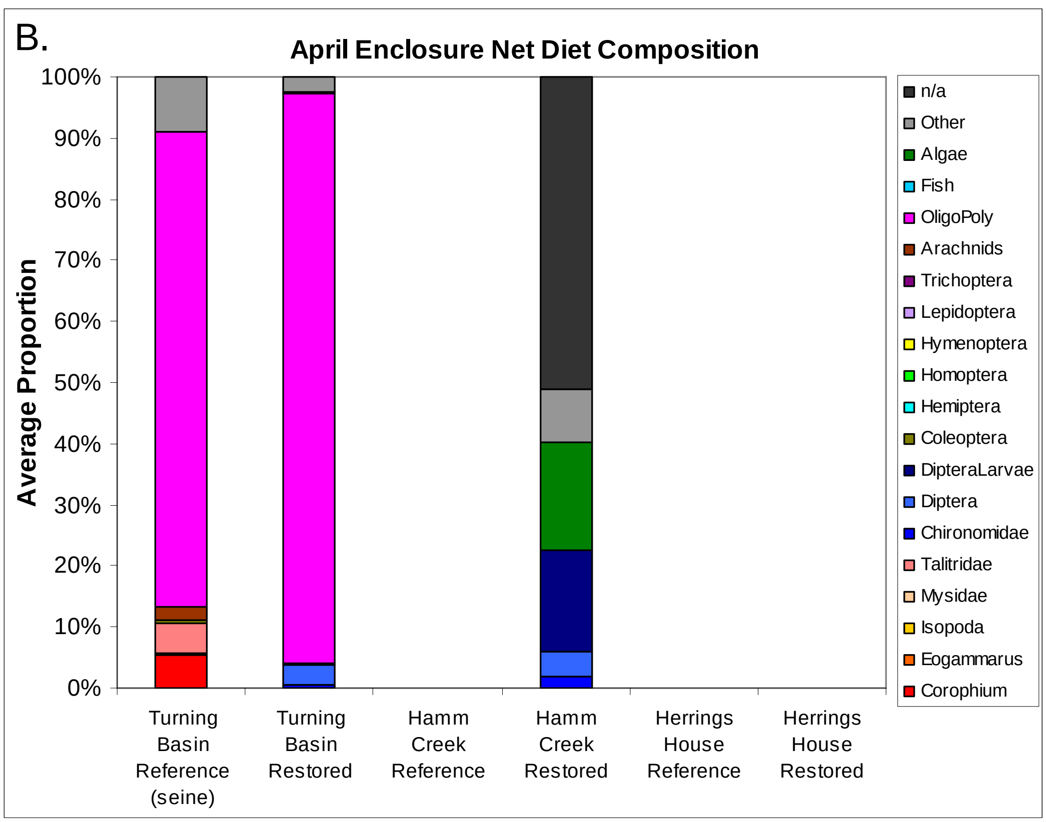
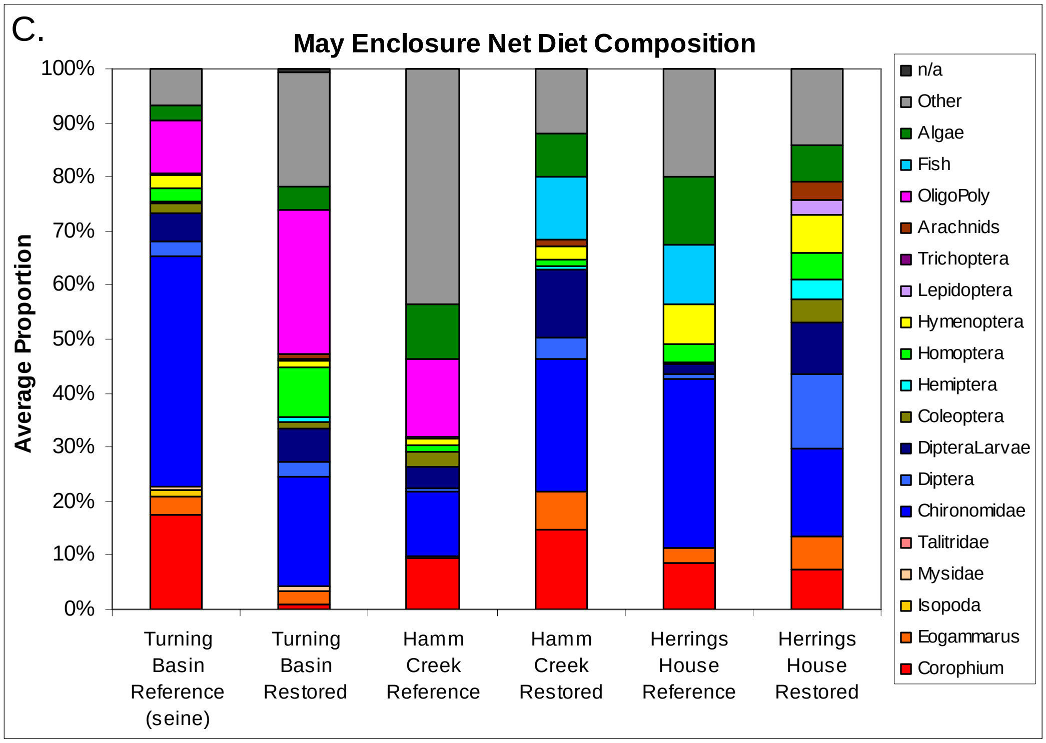


Figure 26. Diet composition (% gravimetric) of bioenergetic categories for juvenile Chinook salmon from enclosure net sampling, averaged for each month. Empty columns indicate no data.



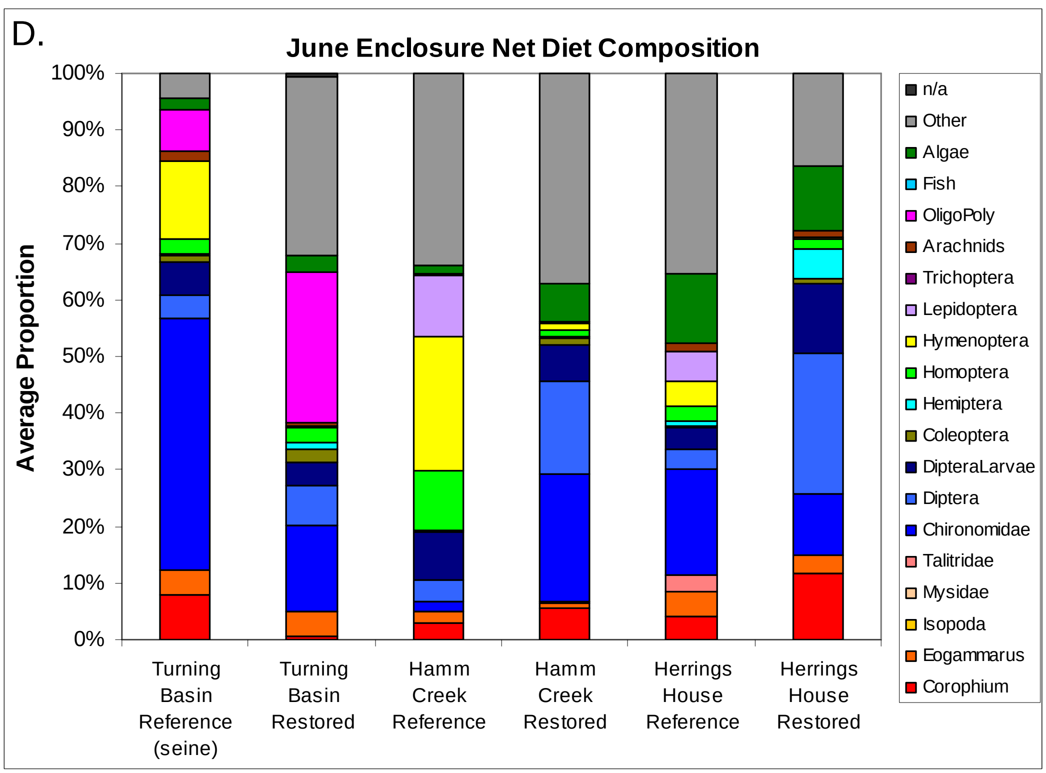


Figure 26 cont. Diet composition (% gravimetric) of bioenergetic categories for juvenile Chinook salmon from enclosure net sampling, averaged for each month.

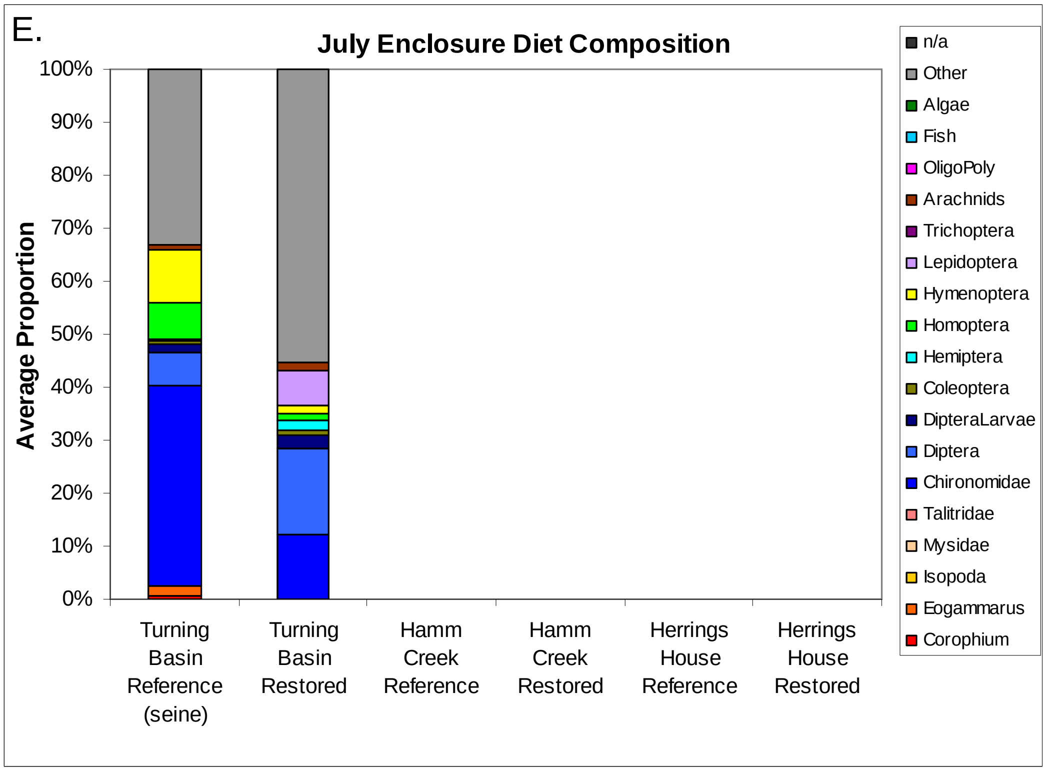
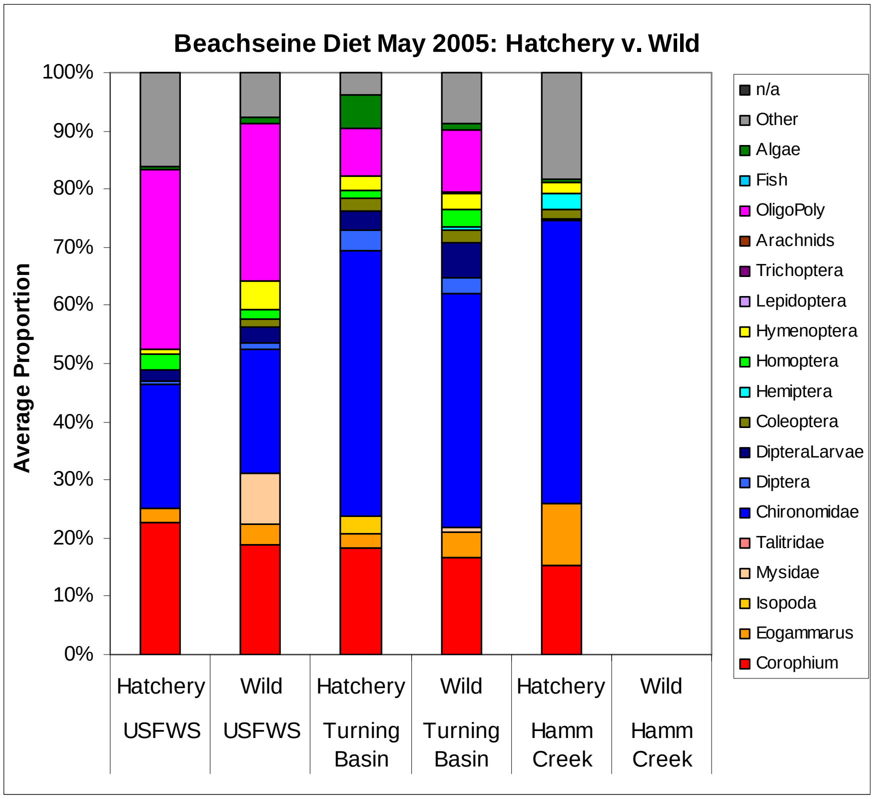


Figure 26 cont. Diet composition (% gravimetric) of bioenergetic categories for juvenile Chinook salmon from enclosure net sampling, averaged for each month. Empty columns indicate no data.



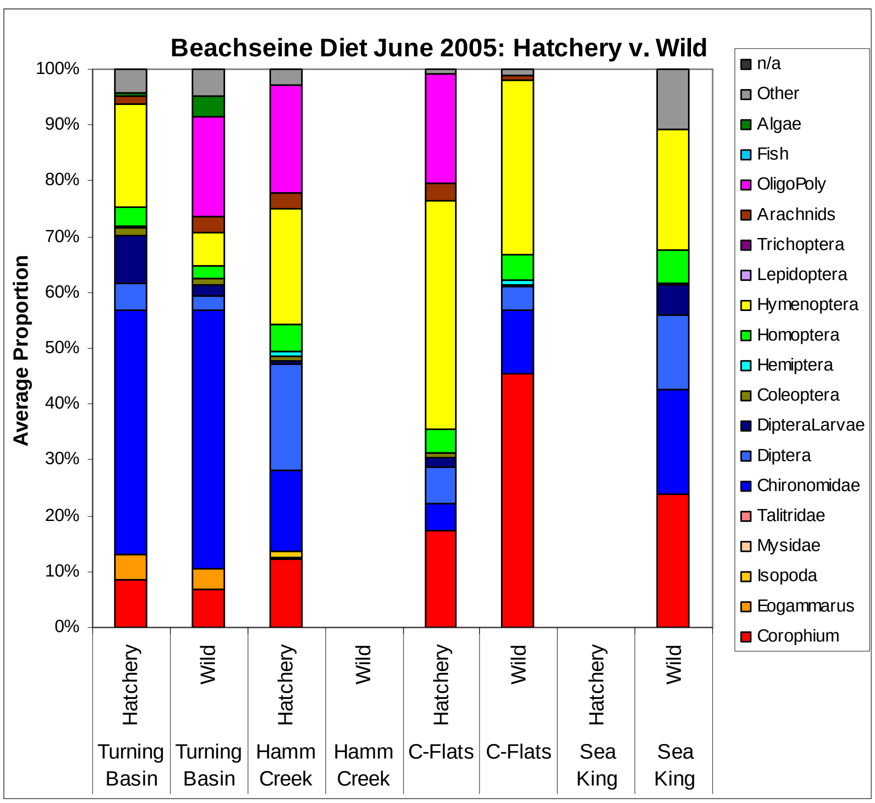


Figure 27. Diet composition (% gravimetric) of bioenergetic categories for hatchery and wild juvenile Chinook salmon from beach seine sampling in May and June. Empty columns indicate no data.

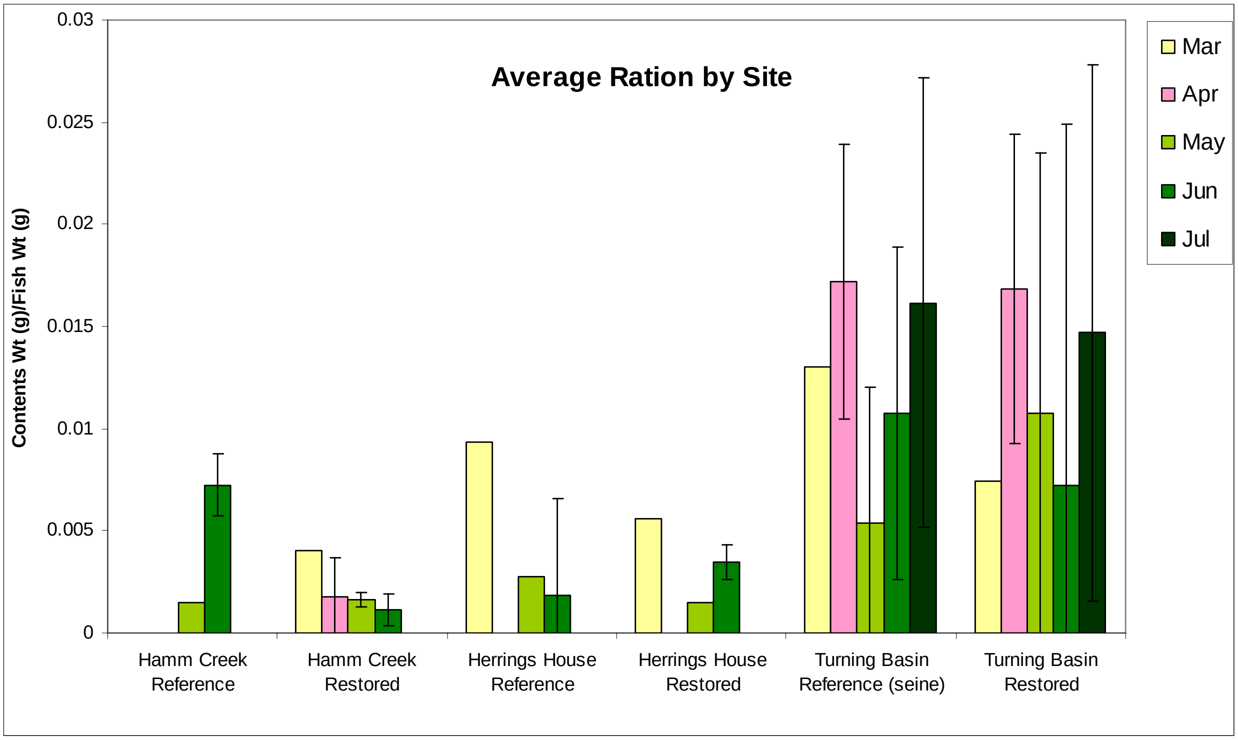


Figure 28. Instantaneous ration of juvenile Chinook salmon captured in the enclosure nets. Error bars are standard deviation.

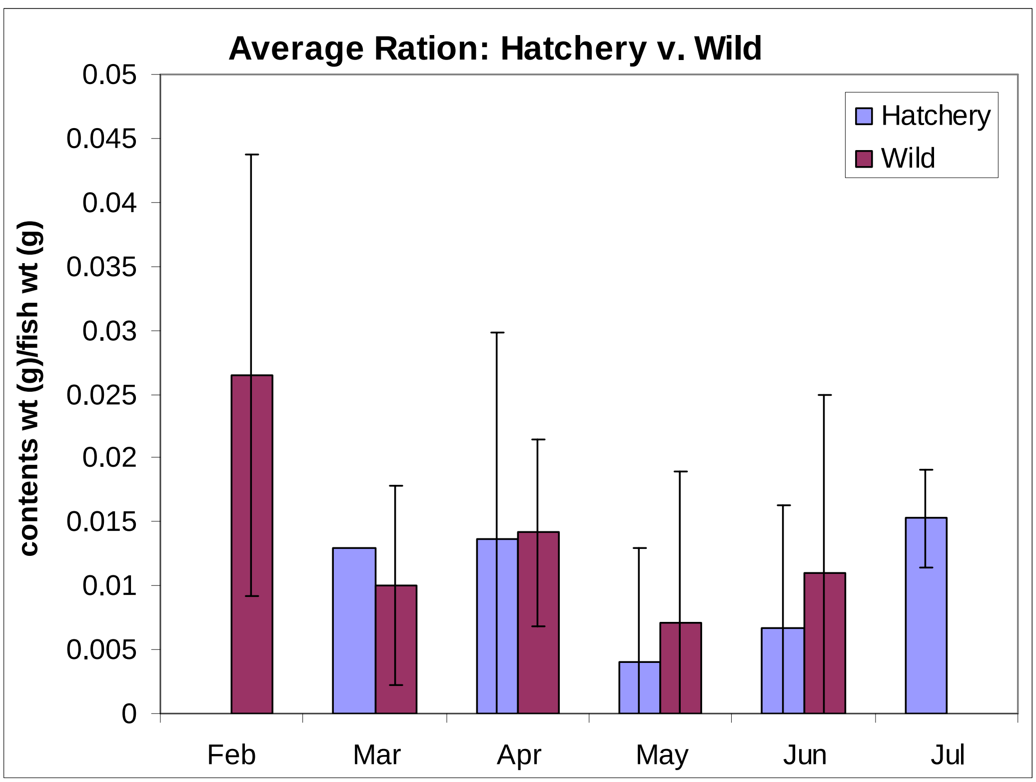


Figure 29. Instantaneous ration of juvenile hatchery and wild Chinook salmon captured in the beach seines. Error bars are standard deviation.

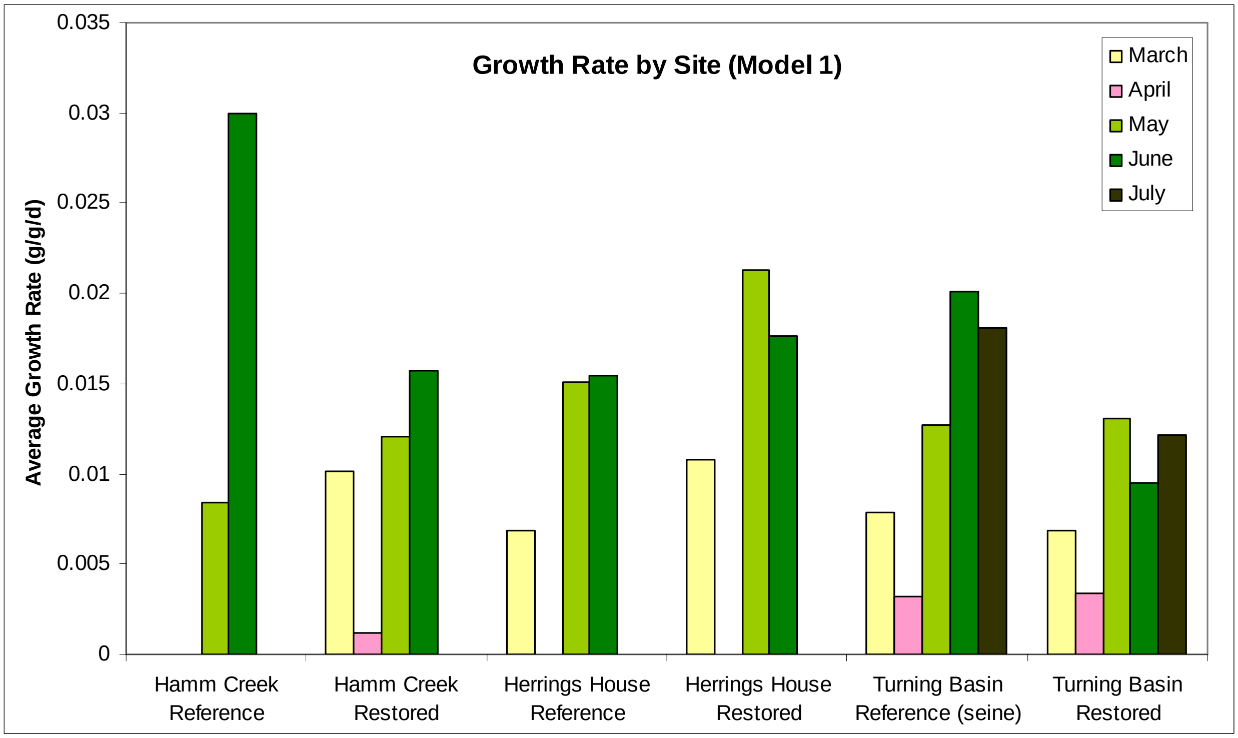


Figure 30. Output of modeled growth from the bioenergetics model for Model 1 of the enclosure net data (standard consumption of P = 0.5).

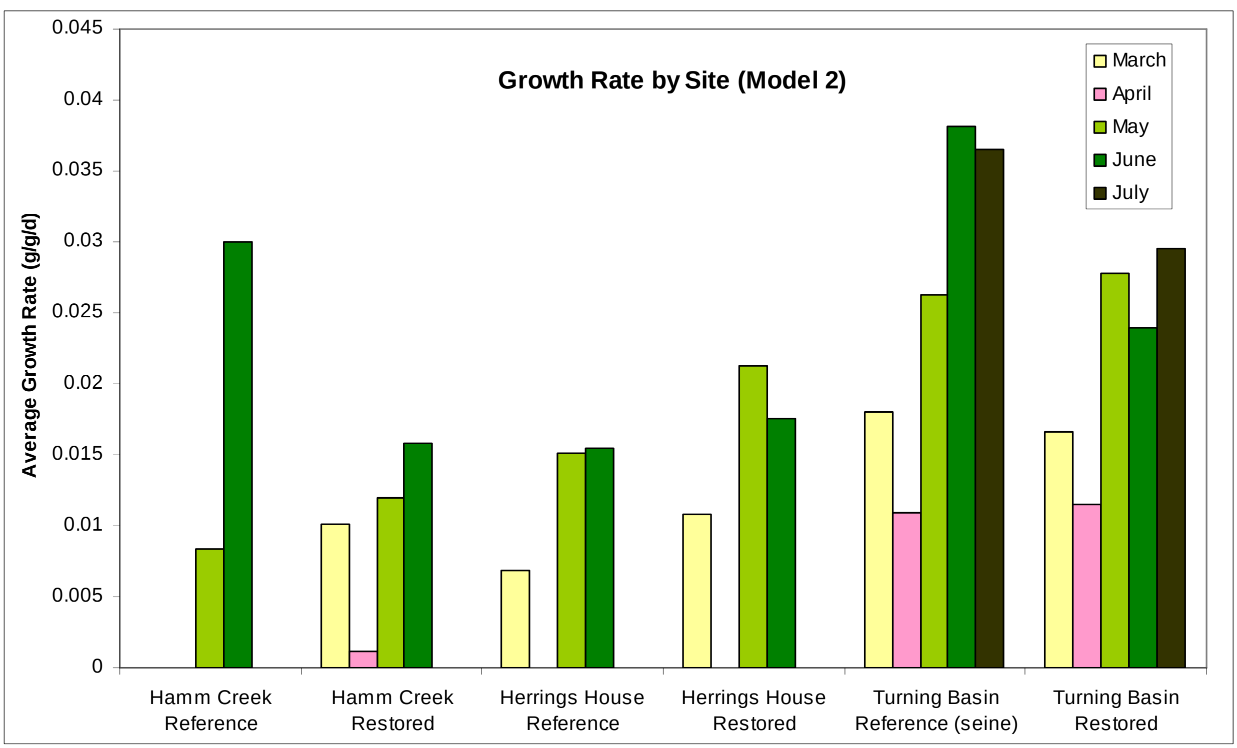


Figure 31. Output of modeled growth from the bioenergetics model for Model 2 of the enclosure net data (consumption adjusted for higher instantaneous ration values at Turning Basin).

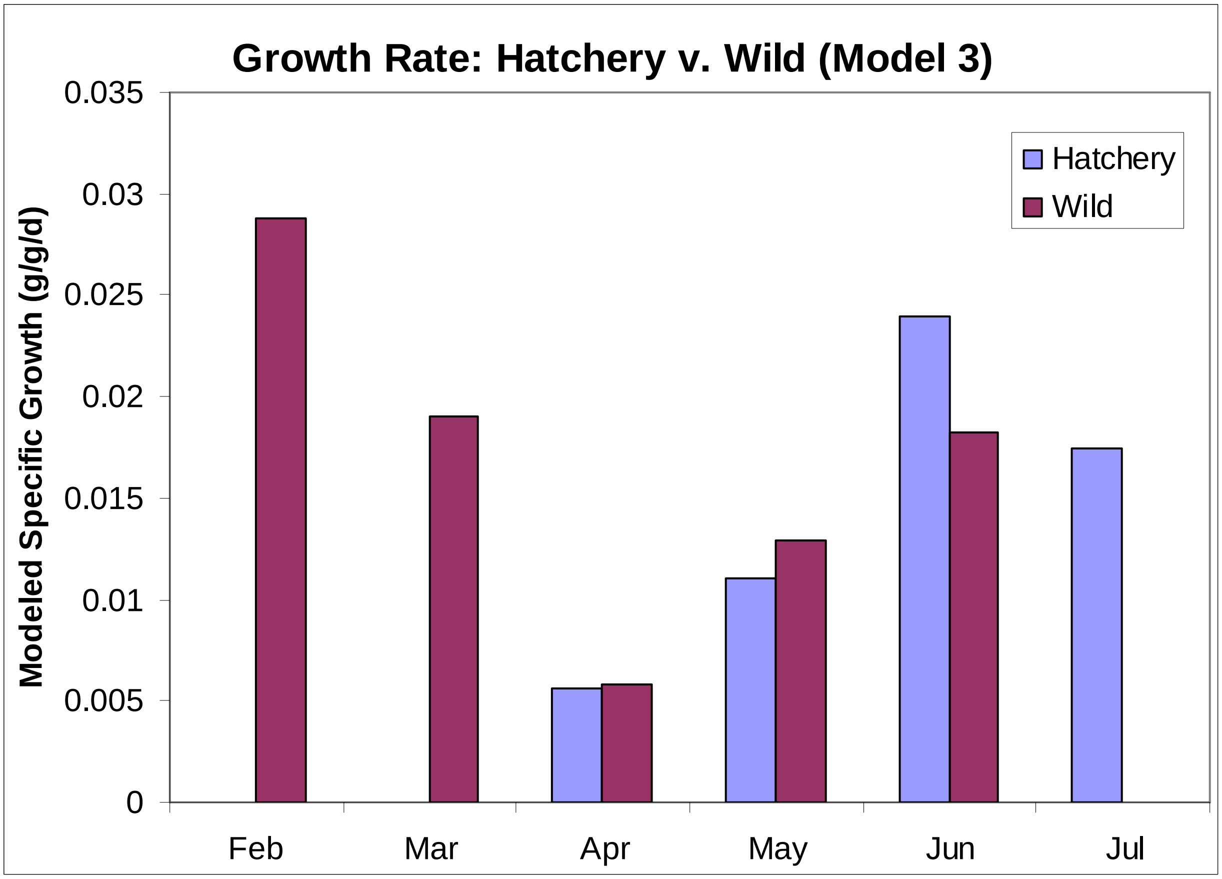


Figure 32. Output of modeled growth from the bioenergetics model for the beach seine data from the general Turning Basin sites (standard consumption of P = 0.5).

Table 1. Prey energy used for the bioenergetics model. Categories in bold were collected in the Duwamish and calculated with bomb calorimetry, other values are from various field samplings and literature values (Gray 2005).

	kJ/g ww
Corophium	3.04
Eogammarus	2.65
Isopoda (Gnorimosphaeroma)	3.46
Mysidae	3.55
Talitridae	3.04
Chironomidae	3.83
Diptera	8.92
DipteraLarvae	2.58
Coleoptera	7.97
Hemiptera	10.93
Homoptera	12.27
Hymenoptera	12.67
Lepidoptera	8.50
Trichoptera	7.76
Arachnids	5.32
OligoPoly (Nereidae)	1.73
Fish	3.57
Algae	3.85
Other	2
n/a	0

Table 2. Bomb calorimetry output for invertebrate taxa in the Duwamish River. Calories per gram of dry weight (cal/g dw) determined from Parr 1425 Semimicro Calorimeter. Kilojoules per gram dry weight (kJ/g dw), dry weight-to-wet weight ratio (dw/ww), and kilojoules per gram of wet weight (kJ/g ww) determined through calculation. Salmon River and literature values are from Gray et al. (2005).

	cal/g dw	kJ/g dw	dw/ww ratio			kJ/g ww	
PREY TYPE	Duwamish R.		Duwamish R.	Salmon R.	Literature	Duwamish R.	Salmon R.
Corophium spp.	4005.31	16.74	0.18	0.23	0.21	3.04	3.09
Eogammarus spp.	3488.26	14.58	0.18	0.27	0.21	2.65	3.10
Isopoda	2954.21	12.35	0.28	0.27	N/A	3.46	2.46
Polychaeta	4639.88	19.39	0.09	0.12	0.18	1.73	1.98

Table 3. Averages of environmental measurements at each site.

	Turning Basin Reference	Turning Basin Restoration	Hamm Creek Reference	Hamm Creek Restoration	Herrings House Reference	Herrings House Restoration
Average of Salinity surface (ppt)	1.5	1.4	1.4	2.4	11.4	11.3
Average of Salinity depth (ppt)	8.4	4.9	7.9	7.6	24.5	19.1
Average of Temp surface (degC)	11.6	11.5	11.3	11.4	12.4	11.8
Average of Temp depth (degC)	11.3	11.6	11.2	11.5	11.2	11.7
Average of Time net deployed (hours)	2.7	3.0	2.5	4.1	3.1	2.4
Average of Max Water Depth @ Net Set (m)	1.8	1.5	1.9	2.5	2.9	1.4

Table 4. Common and scientific names of sampled fish, with overall average lengths (forklength for salmonids and smelt, standard length for other fish), and total numbers sampled.

Common Name	Scientific Name	Average Length (mm)	Total Number of Sampled Fish
Chinook Salmon	*Oncorhynchus tshawytscha*	unmarked fry 53.6	82
		unmarked smolts 80.9	81
		marked 80.6	553
Coho Salmon	*Oncorhynchus kisutch*	unmarked 118.3	163
		marked 143.9	226
Chum Salmon	*Oncorhynchus keta*	42.8	1921
Pink Salmon	*Onchorhynchus gorbuscha*	30.0	1
Sockeye Salmon	*Oncorhynchus nerka*	48.0	4
Steelhead Trout	*Oncorhynchus mykiss*	unmarked 222.5	3
		marked 179	6
Cutthroat Trout	*Onchorhynchus clarki*	238.0	1
Shiner Perch	*Cymatogaster aggregata*	79.0	8321
Pile Perch	*Rhacochilus vacca*	219.8	7
Threespine Stickleback	*Gasterosteus aculeatus*	39.7	1233
Surf Smelt	*Hypomesus pretiosus pretiosus*	141.7	40
American Shad	*Alosa sapidissima*	127.0	2
Largescale Sucker	*Catostomus macrocheilus*	42.3	7
Bluegill	*Lepomis macrochirus*	34.0	4
Peamouth Chub	*Mylocheilus caurinus*	31.9	1
Prickly Sculpin	*Cottus asper*	66.4	111
Tidepool Sculpin	*Oligocottus maculosus*	51.0	3
Staghorn Sculpin	*Leptocottus armatus*	48.9	587
Sculpin unid./juv.	Cottidae	36.0	1281
Saddleback Gunnel	*Pholis ornata*	149.6	5
Crescent Gunnel	*Pholis laeta*	149.0	4
Snake prickleback	*Lumpenus sagitta*	223.8	4
Starry Flounder	*Platichthys stellatus*	57.7	913
Lamprey	*Lampetra sp.*	431.8	1

Table 5. Taxa richness of fish catches at each site.

	Taxa Richness
Turning Basin Restored	13
Turning Basin Reference	8
Hamm Creek Restored	15
Hamm Creek Reference	10
Herrings House Restored	13
Herrings House Reference	13

Table 6. Summary of p-values from univariate ANOVA analysis on log-transformed Chinook and total fish densities between restored and reference sites at each paired location. Significant differences ($p < 0.05$) are highlighted in bold.

	Chinook densities	Total densities
Turning Basin	**0.009**	0.614
Hamm Creek	0.796	0.807
Herrings House	0.861	0.068

Table 7. Summary statistics using multivariate analysis on fish densities. ANOSIM is equivalent to a univariate ANOVA, significant differences ($p < 0.05$) are highlighted in bold. SIMPER analyzes the species that have the largest contributions to statistical differences (included if greater than 15%).

2-way ANOSIM on Site x Week

	R-value	p value
Week	0.417	**< 0.001**
Site	0.151	**< 0.007**

1-way separate ANOSIMs on each paired site

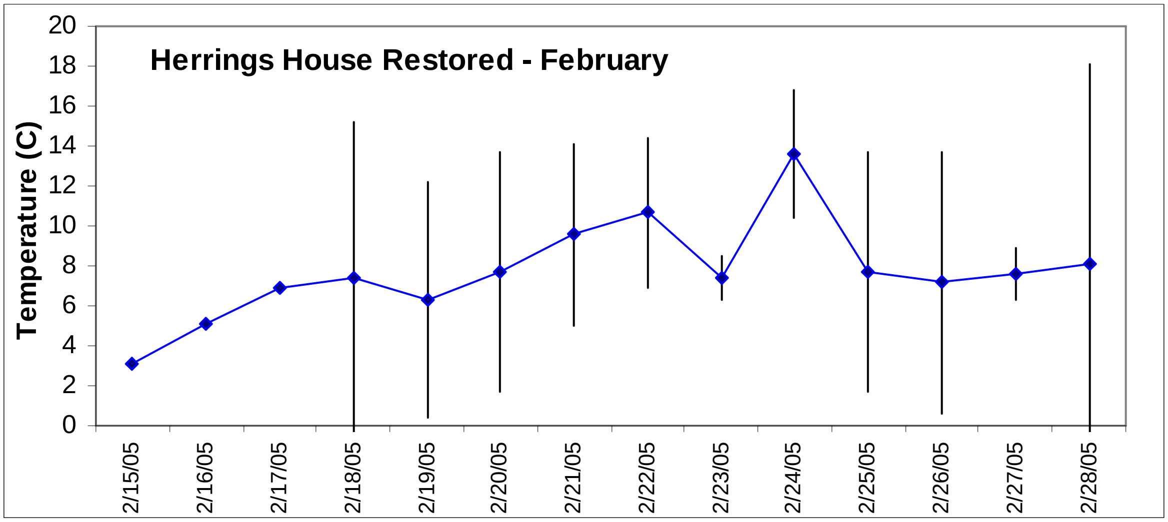
	R-value	p value
Turning Basin	0.118	**< 0.044**
Hamm Creek	0.065	< 0.155
Herrings House	0.223	**< 0.013**

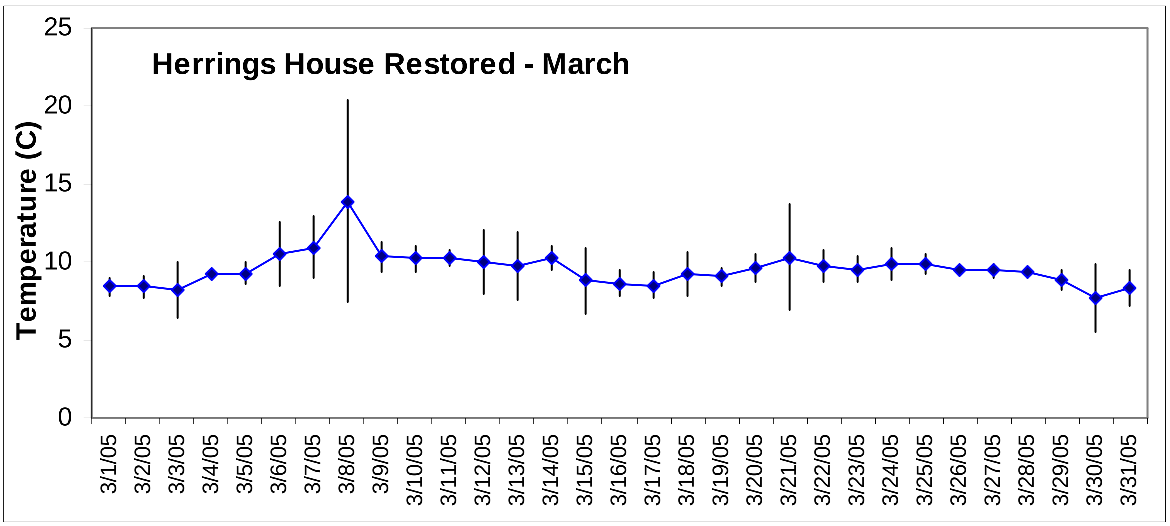
SIMPER Analysis

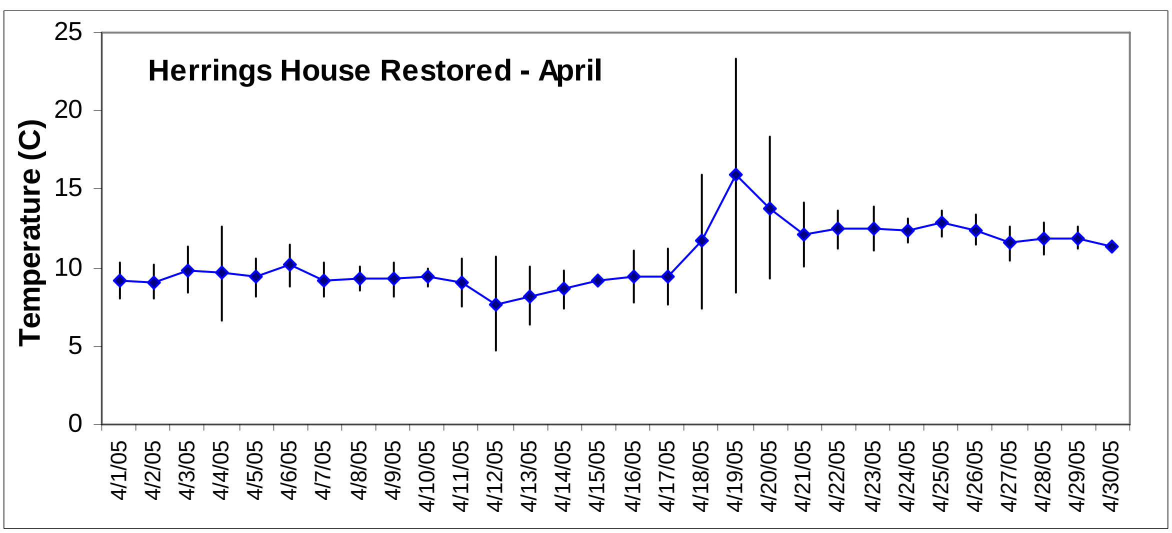
	Average densities of log-transformed data		
	Turning Basin Reference	Turning Basin Restored	% contribution
Starry Flounder	4.06	2.42	19.1
Sculpin	3.6	3.04	18.5
Chum	1.33	1.96	18.1
Chinook	0.54	2.25	15.4

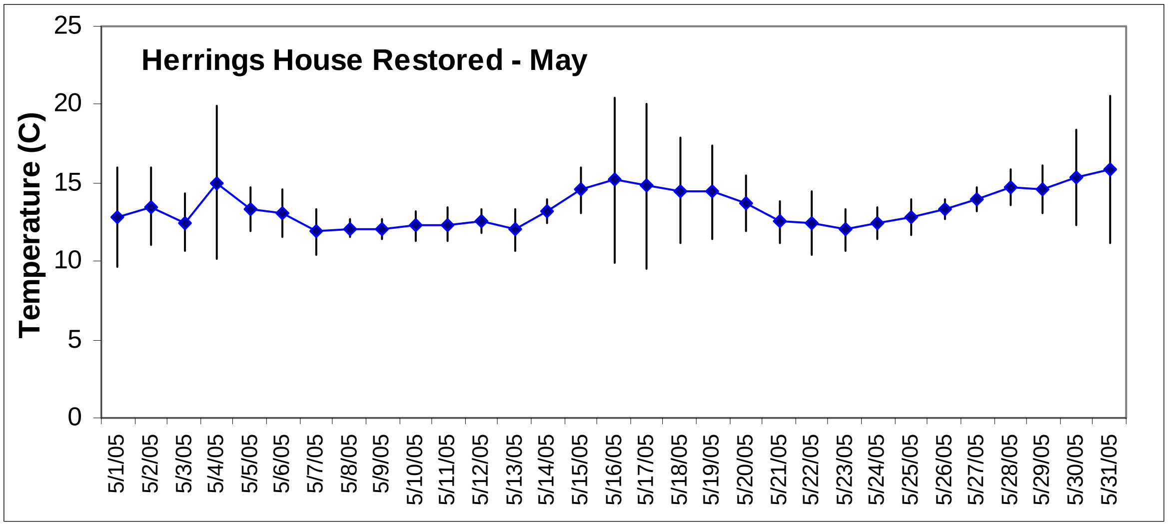
	Herrings House Reference	Herrings House Restored	% contribution
Shiner Perch	2.57	3.62	19.3
Sculpin	4.6	2.02	17.7

Appendix A. Average daily water temperatures at each site, with standard deviations.








Herrings House Restored - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
5/20/05
5/21/05
5/22/05
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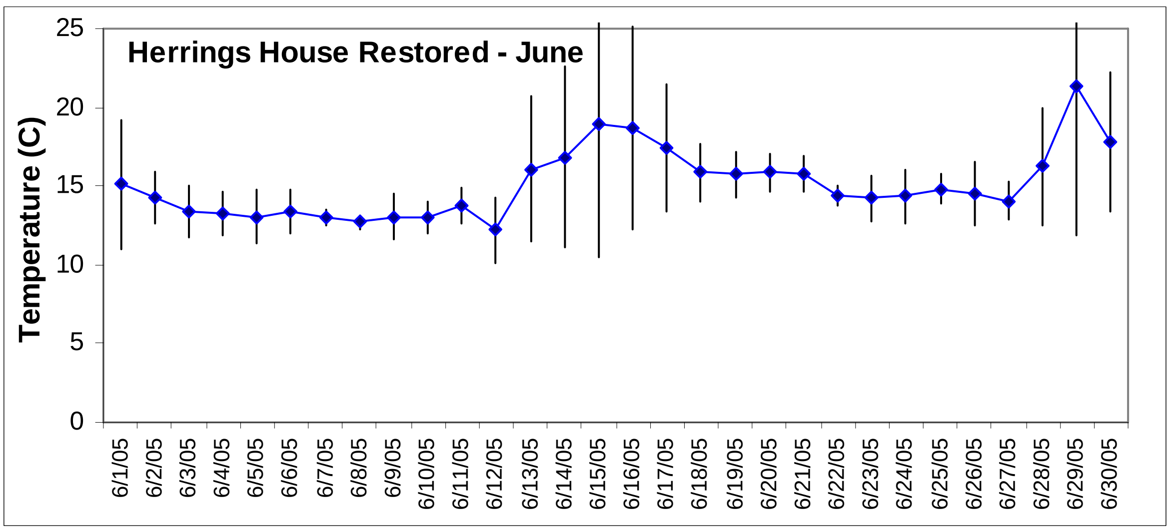
5/30/05
5/31/05


Herrings House Restored - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
6/18/05
6/19/05
6/20/05
6/21/05
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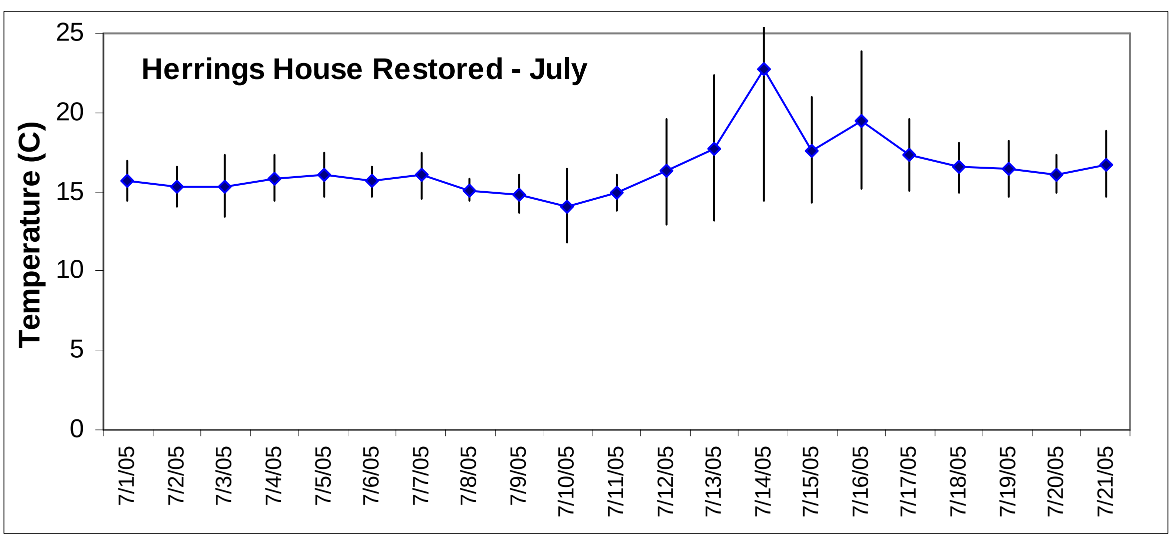
6/29/05
6/30/05


Herrings House Restored - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
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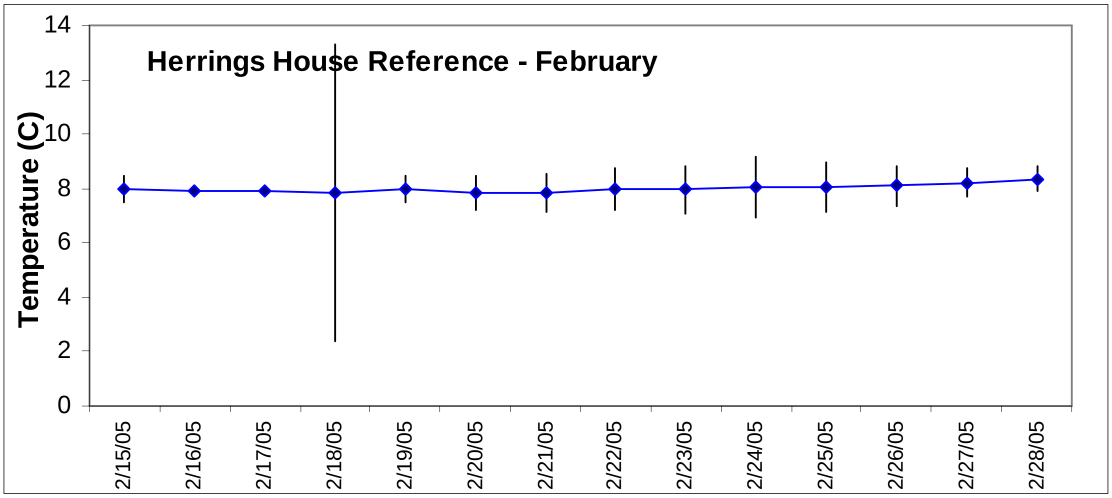
7/20/05
7/21/05


Herrings House Reference - February
Temperature (C)
14
12
10
8
6
4
2
0
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
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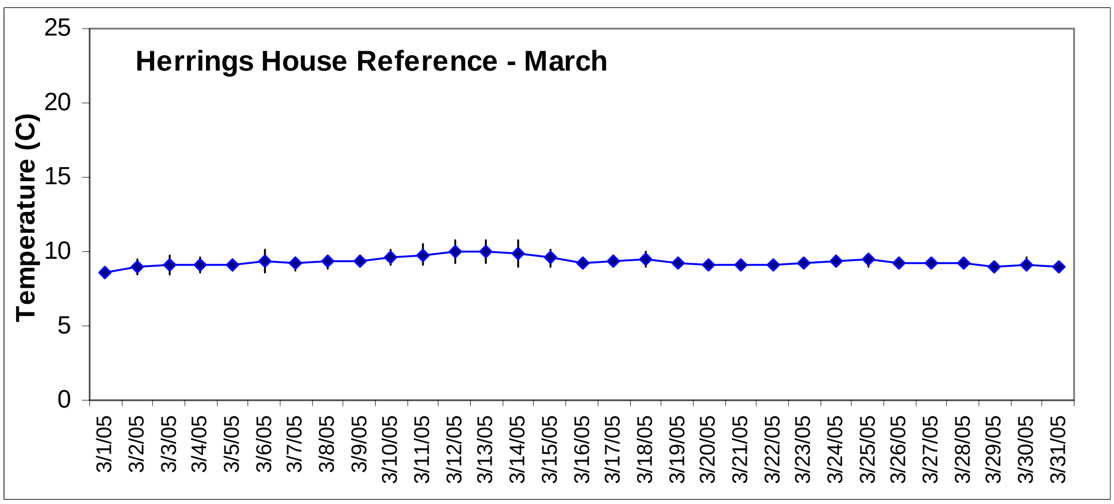
2/27/05
2/28/05


Herrings House Reference - March
Temperature (C)
25
20
15
10
5
0
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
3/13/05
3/14/05
3/15/05
3/16/05
3/17/05
3/18/05
3/19/05
3/20/05
3/21/05
3/22/05
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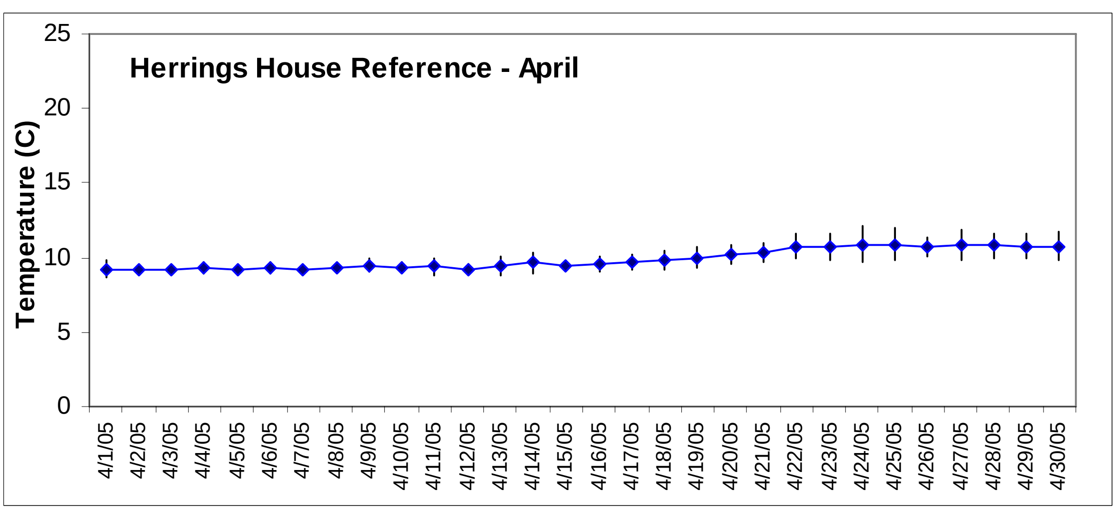
3/30/05
3/31/05


Herrings House Reference - April
Temperature (C)
25
20
15
10
5
0
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
4/11/05
4/12/05
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4/14/05
4/15/05
4/16/05
4/17/05
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4/20/05
4/21/05
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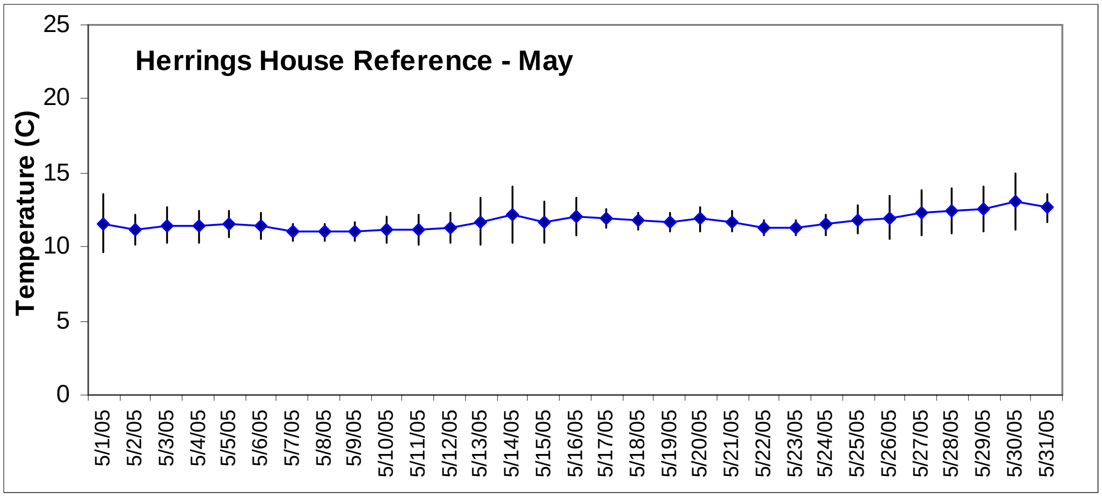
4/29/05
4/30/05


Herrings House Reference - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
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5/15/05
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5/22/05
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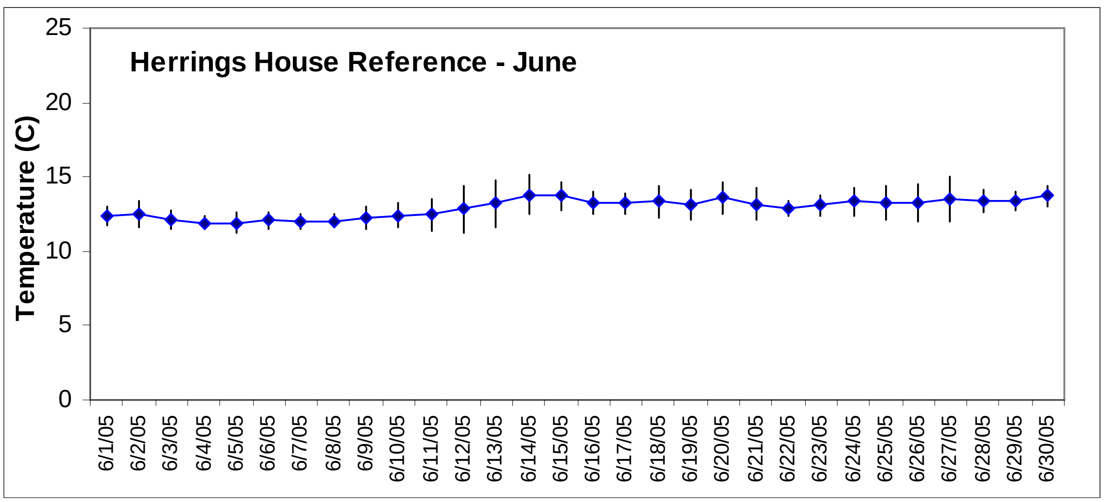
5/29/05
5/30/05
5/31/05


Herrings House Reference - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
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6/21/05
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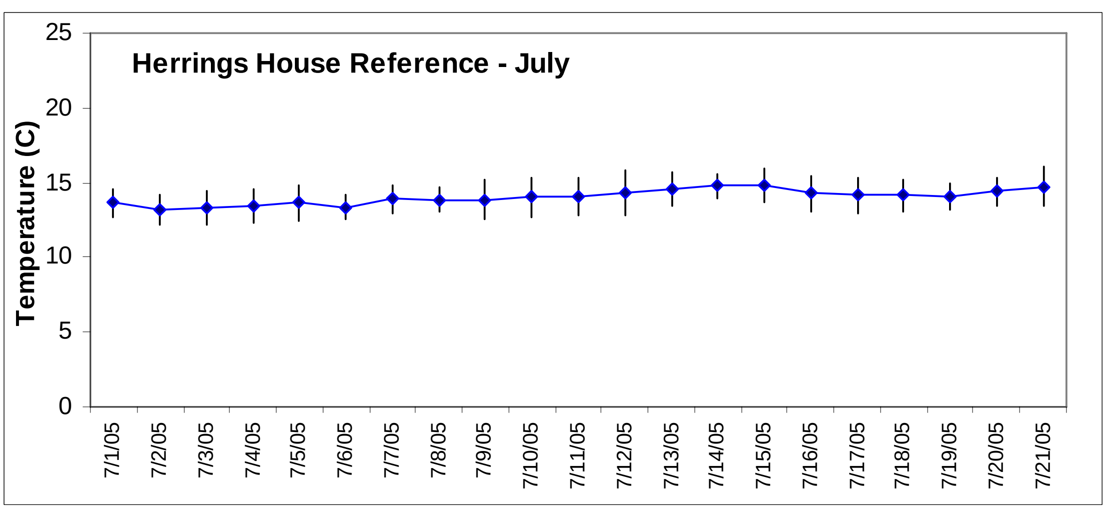
6/29/05
6/30/05


Herrings House Reference - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
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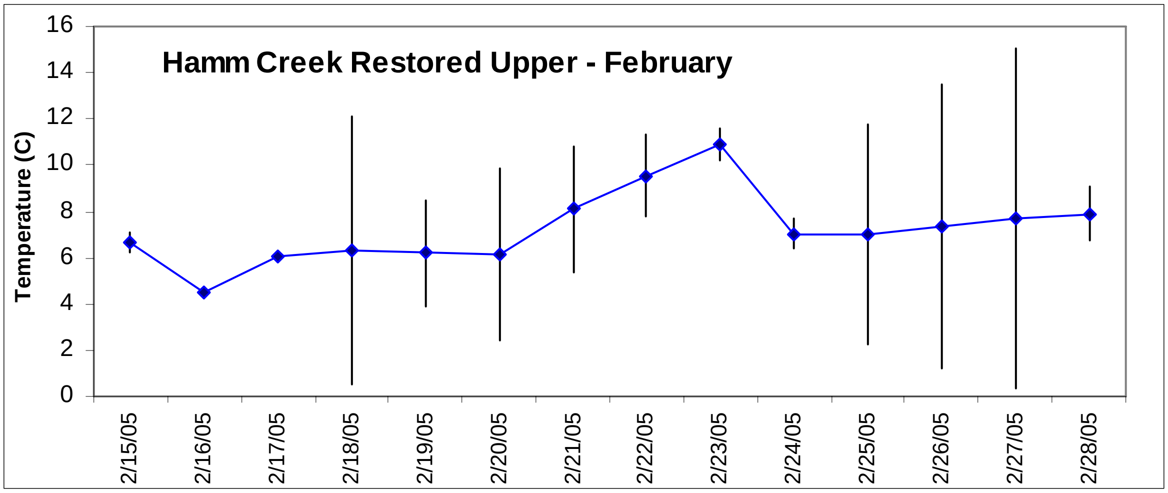
7/20/05
7/21/05


Hamm Creek Restored Upper - February
Temperature (C)
16
14
12
10
8
6
4
2
0
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
2/20/05
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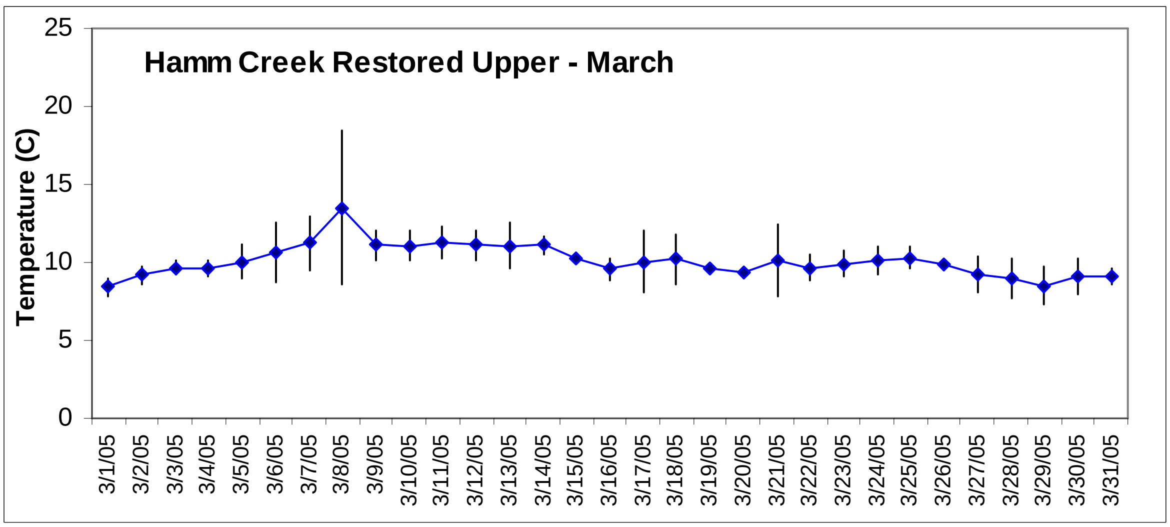
2/27/05
2/28/05


Hamm Creek Restored Upper - March
Temperature (C)
25
20
15
10
5
0
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
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3/14/05
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3/18/05
3/19/05
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3/22/05
3/23/05
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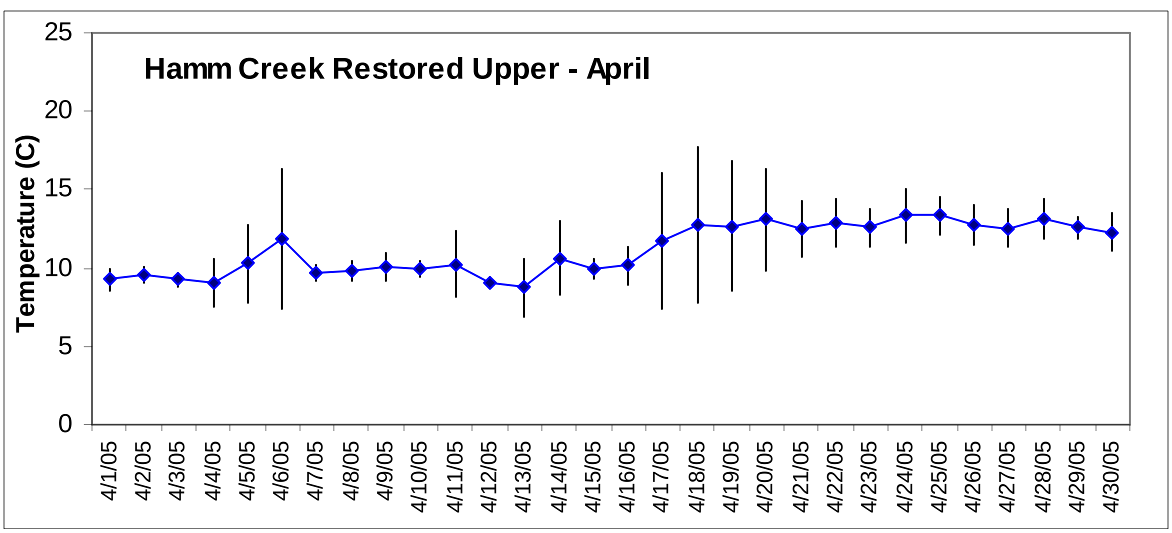
3/27/05
3/28/05
3/29/05
3/30/05
3/31/05


Hamm Creek Restored Upper - April
Temperature (C)
25
20
15
10
5
0
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
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4/12/05
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4/21/05
4/22/05
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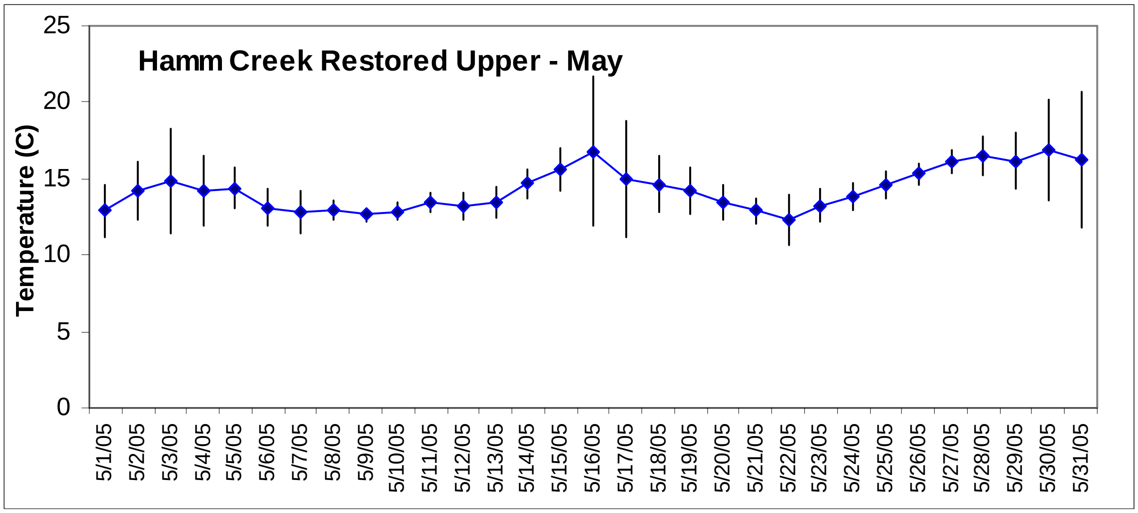
4/28/05
4/29/05
4/30/05


Hamm Creek Restored Upper - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
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5/22/05
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5/27/05
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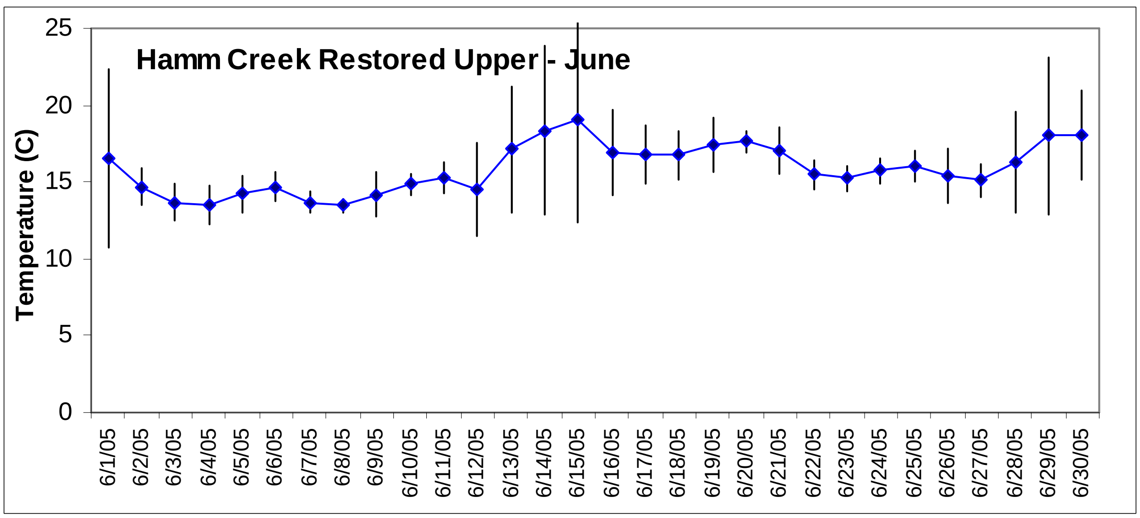
5/29/05
5/30/05
5/31/05


Hamm Creek Restored Upper - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
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6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
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6/19/05
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6/21/05
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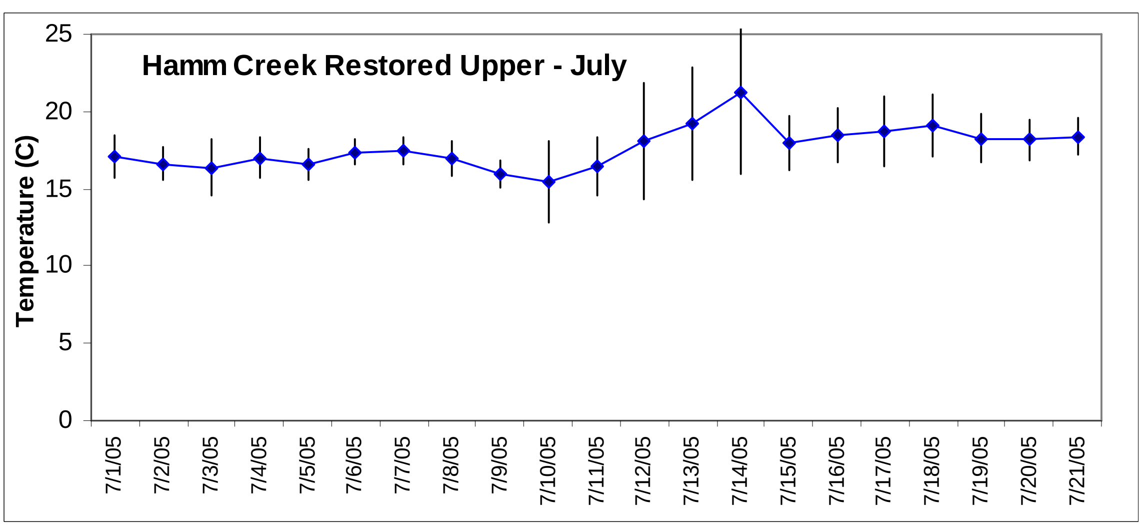
6/27/05
6/28/05
6/29/05
6/30/05


Hamm Creek Restored Upper - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
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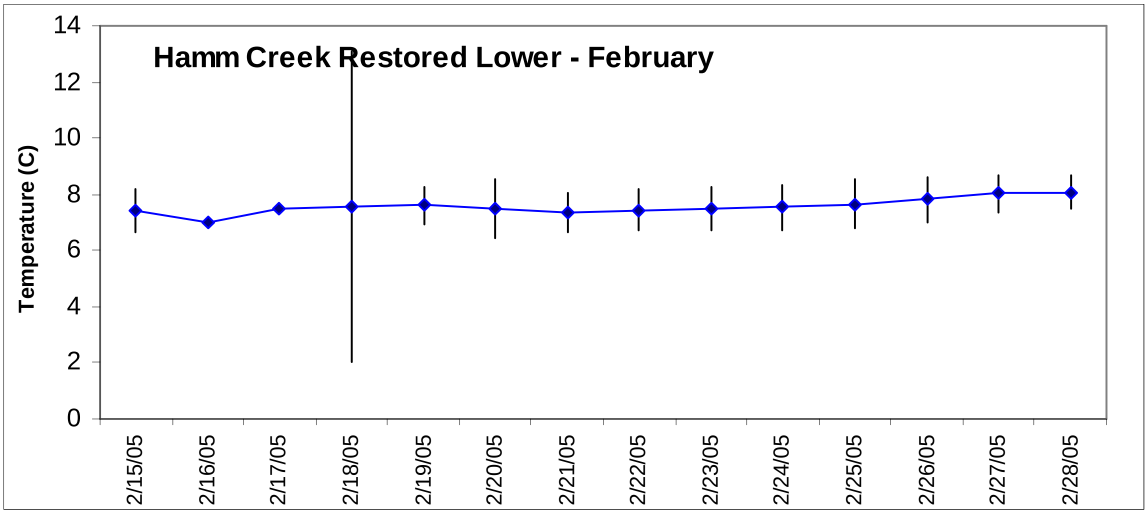
7/20/05
7/21/05


Hamm Creek Restored Lower - February
Temperature (C)
0
2
4
6
8
10
12
14
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
2/20/05
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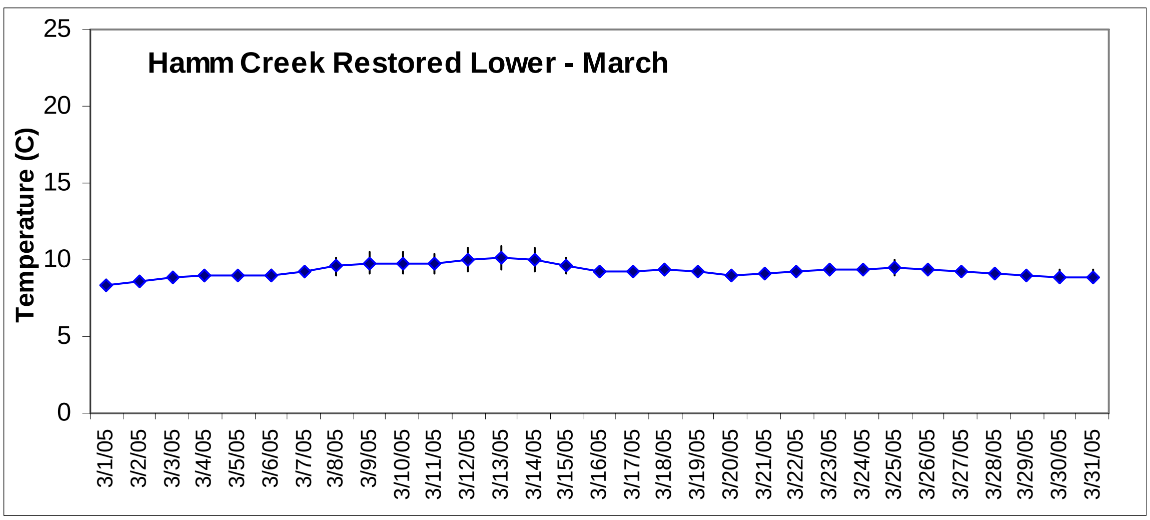
2/27/05
2/28/05


Hamm Creek Restored Lower - March
Temperature (C)
0
5
10
15
20
25
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
3/13/05
3/14/05
3/15/05
3/16/05
3/17/05
3/18/05
3/19/05
3/20/05
3/21/05
3/22/05
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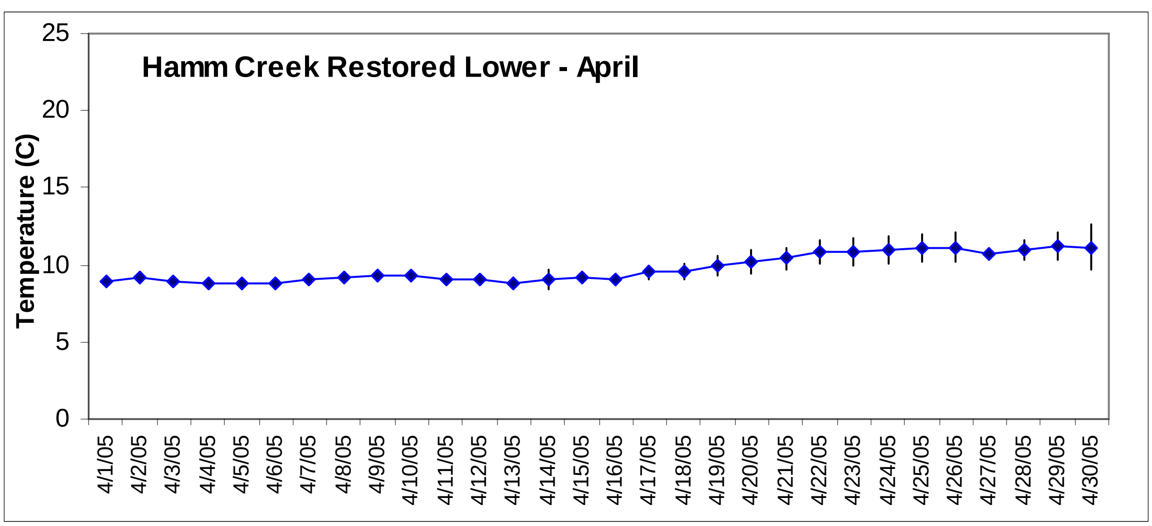
3/30/05
3/31/05


Hamm Creek Restored Lower - April
Temperature (C)
0
5
10
15
20
25
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
4/11/05
4/12/05
4/13/05
4/14/05
4/15/05
4/16/05
4/17/05
4/18/05
4/19/05
4/20/05
4/21/05
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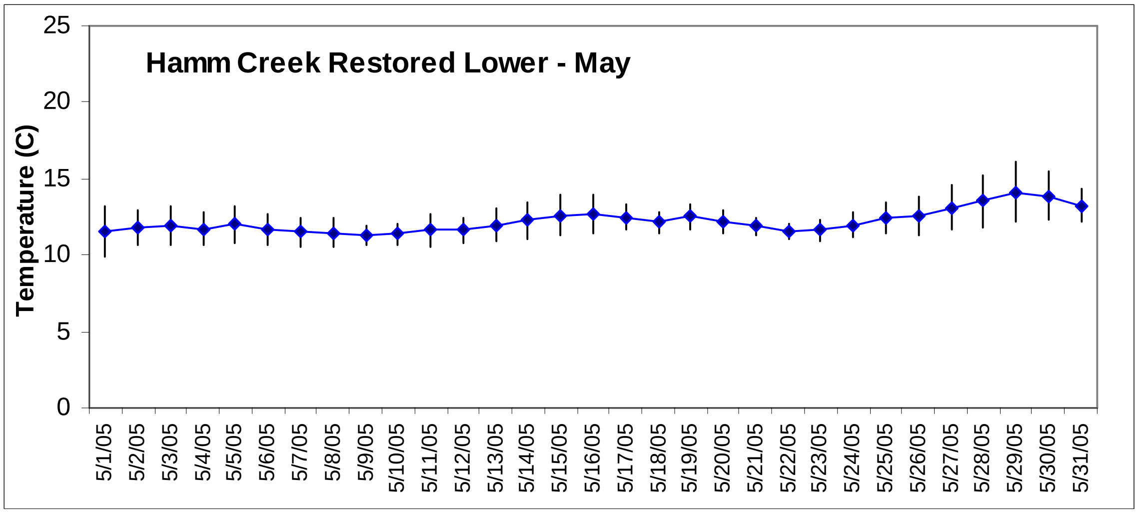
4/29/05
4/30/05


Hamm Creek Restored Lower - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
5/20/05
5/21/05
5/22/05
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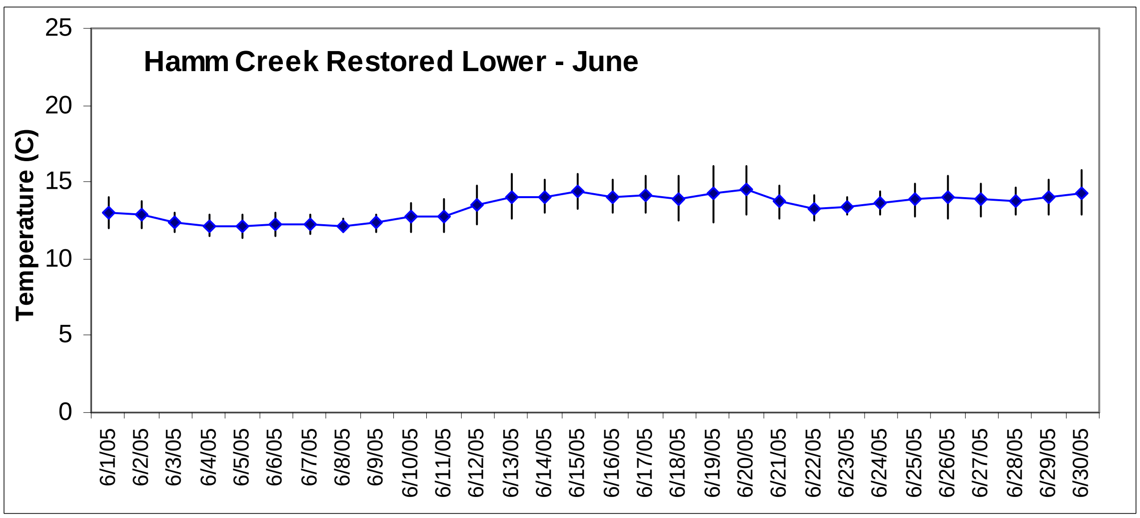
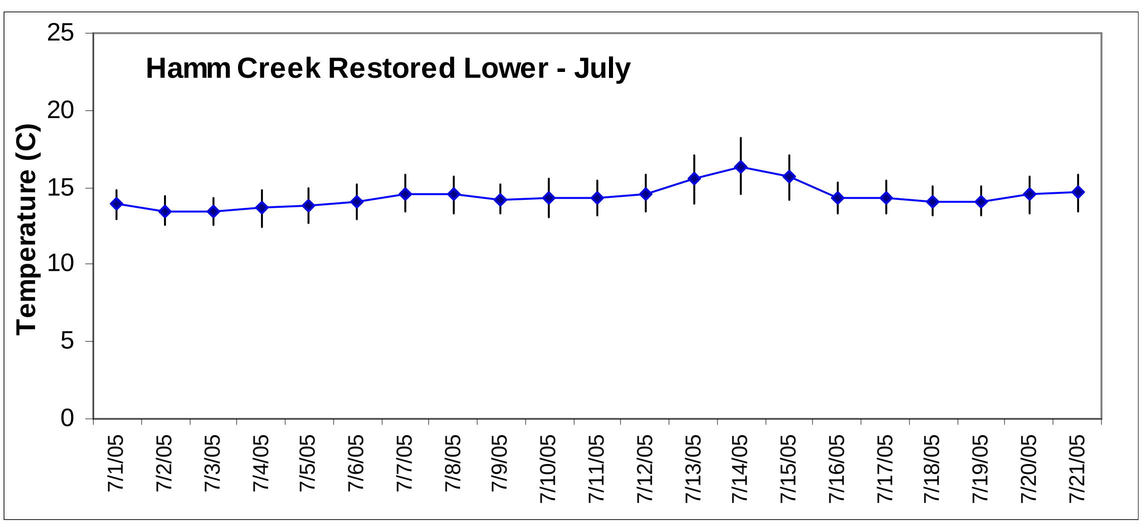
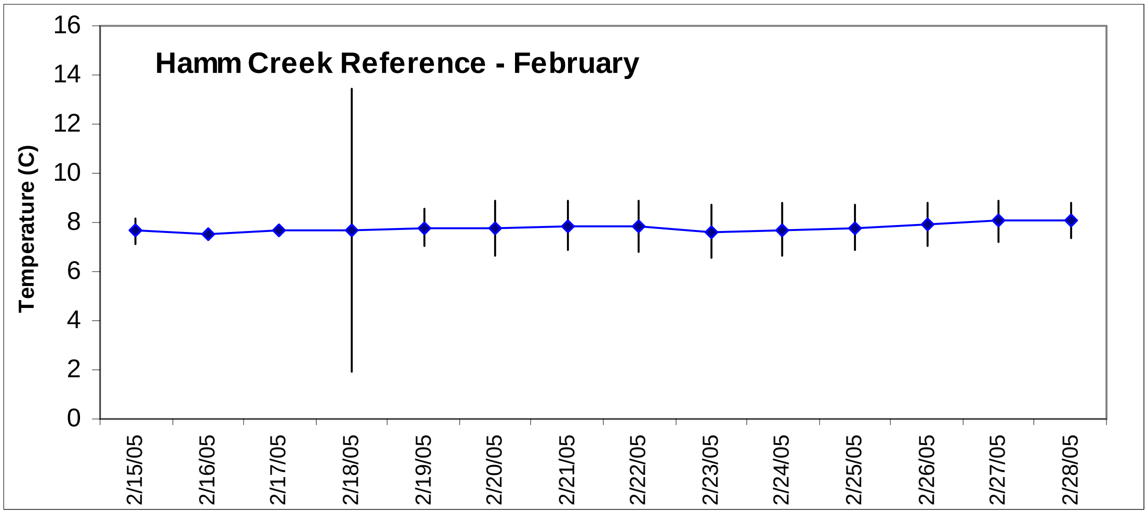
5/30/05
5/31/05


Hamm Creek Restored Lower - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
6/18/05
6/19/05
6/20/05
6/21/05
6/22/05
6/23/05
6/24/05
6/25/05
6/26/05
6/27/05
6/28/05
6/29/05
6/30/05


Hamm Creek Restored Lower - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
7/13/05
7/14/05
7/15/05
7/16/05
7/17/05
7/18/05
7/19/05
7/20/05
7/21/05


Hamm Creek Reference - February
Temperature (C)
16
14
12
10
8
6
4
2
0
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
2/20/05
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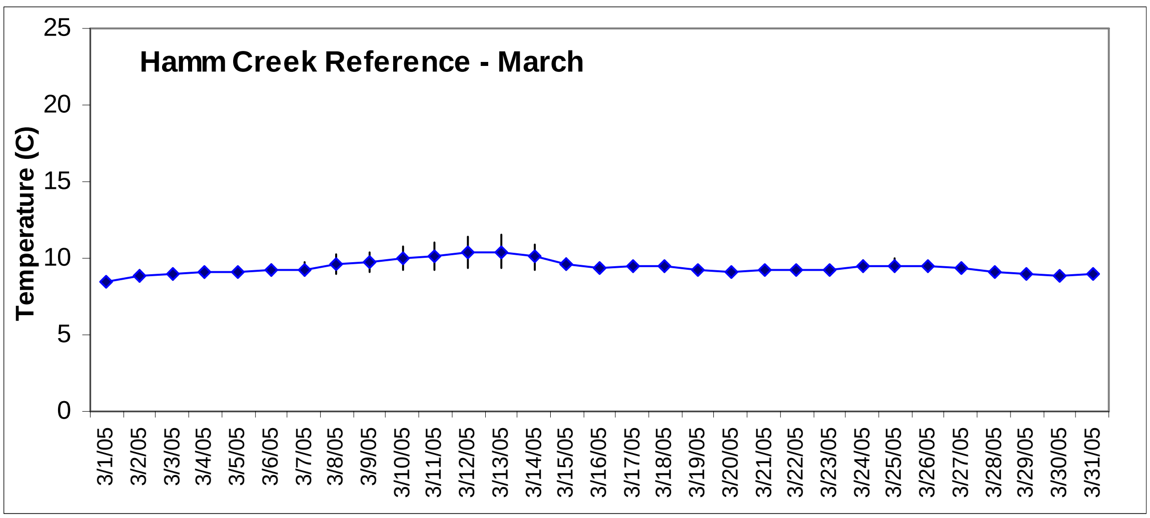
2/24/05
2/25/05
2/26/05
2/27/05
2/28/05


Hamm Creek Reference - March
Temperature (C)
25
20
15
10
5
0
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
3/13/05
3/14/05
3/15/05
3/16/05
3/17/05
3/18/05
3/19/05
3/20/05
3/21/05
3/22/05
3/23/05
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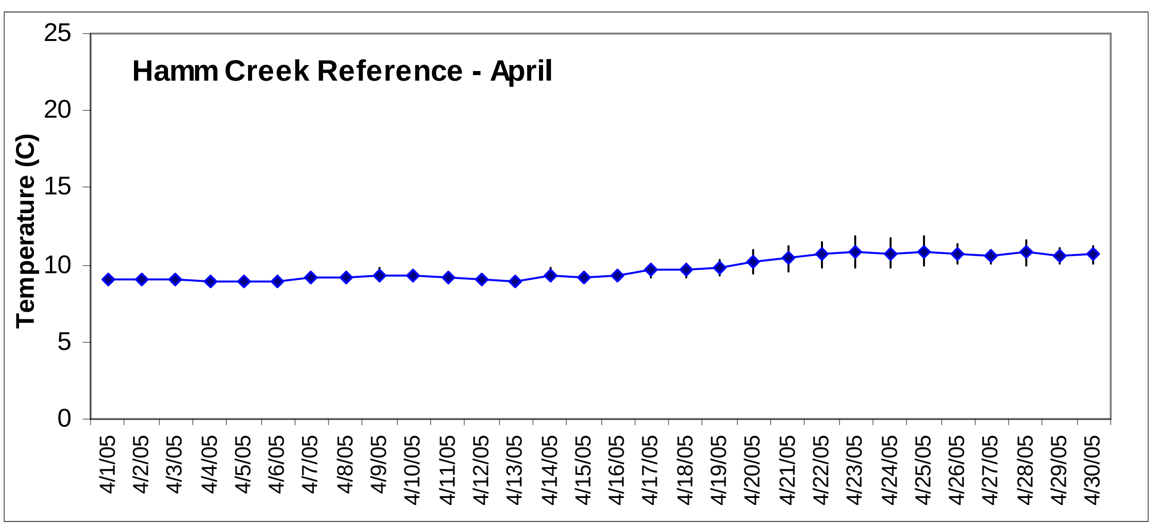
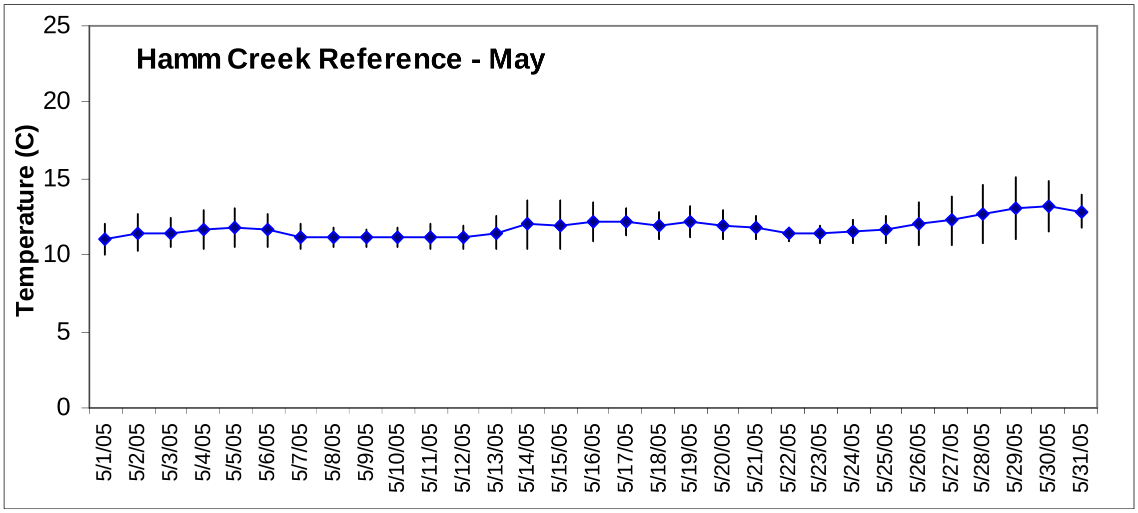
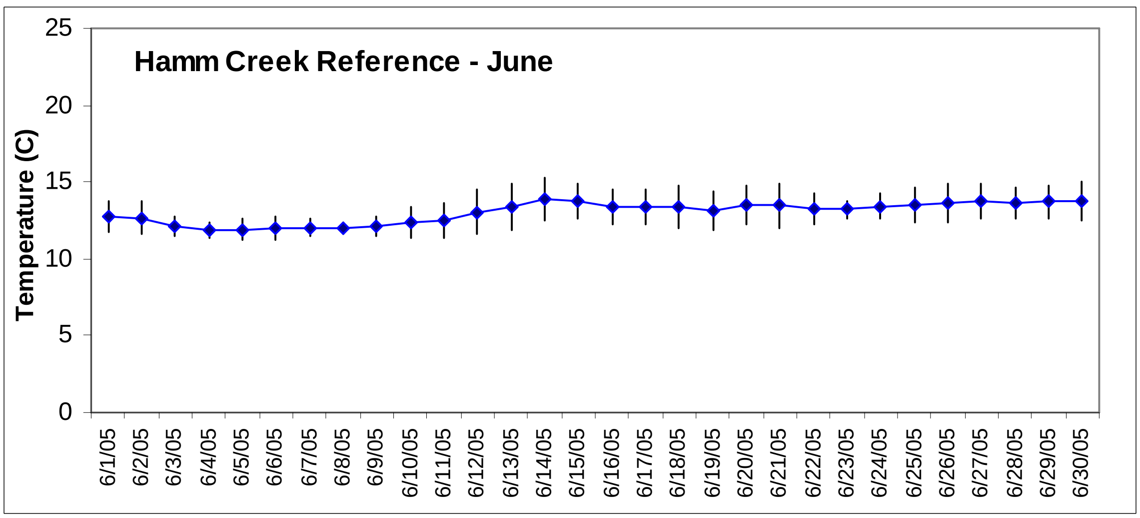
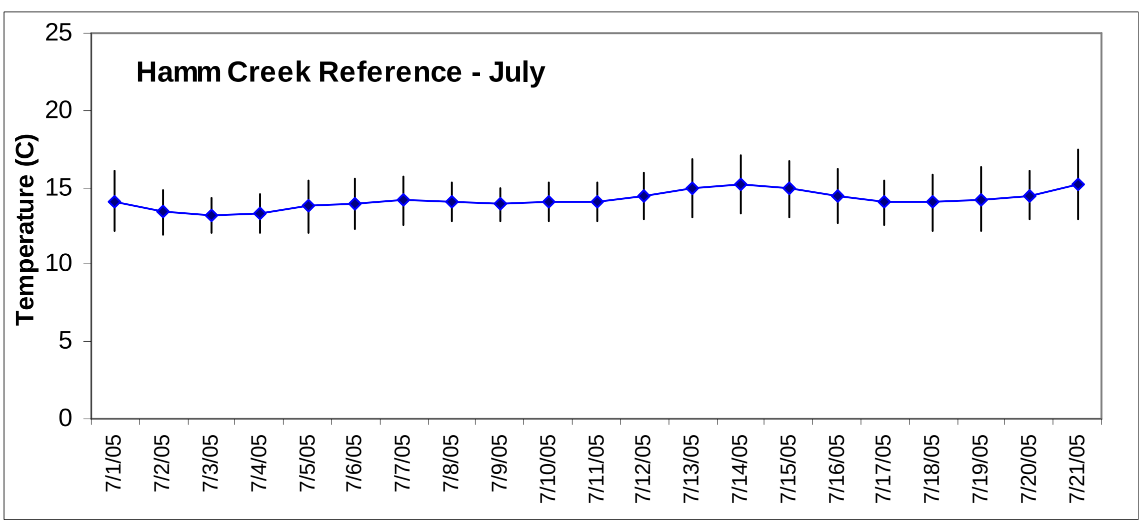
3/29/05
3/30/05
3/31/05


Hamm Creek Reference - April
Temperature (C)
25
20
15
10
5
0
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
4/11/05
4/12/05
4/13/05
4/14/05
4/15/05
4/16/05
4/17/05
4/18/05
4/19/05
4/20/05
4/21/05
4/22/05
4/23/05
4/24/05
4/25/05
4/26/05
4/27/05
4/28/05
4/29/05
4/30/05


Hamm Creek Reference - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
5/20/05
5/21/05
5/22/05
5/23/05
5/24/05
5/25/05
5/26/05
5/27/05
5/28/05
5/29/05
5/30/05
5/31/05


Hamm Creek Reference - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
6/18/05
6/19/05
6/20/05
6/21/05
6/22/05
6/23/05
6/24/05
6/25/05
6/26/05
6/27/05
6/28/05
6/29/05
6/30/05


Hamm Creek Reference - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
7/13/05
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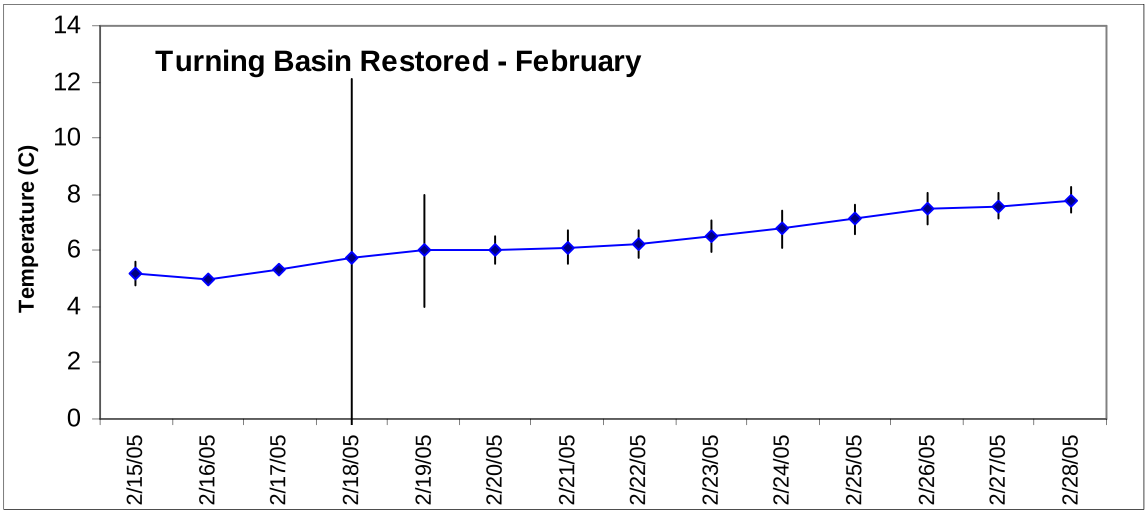
7/16/05
7/17/05
7/18/05
7/19/05
7/20/05
7/21/05


Turning Basin Restored - February
Temperature (C)
14
12
10
8
6
4
2
0
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
2/20/05
2/21/05
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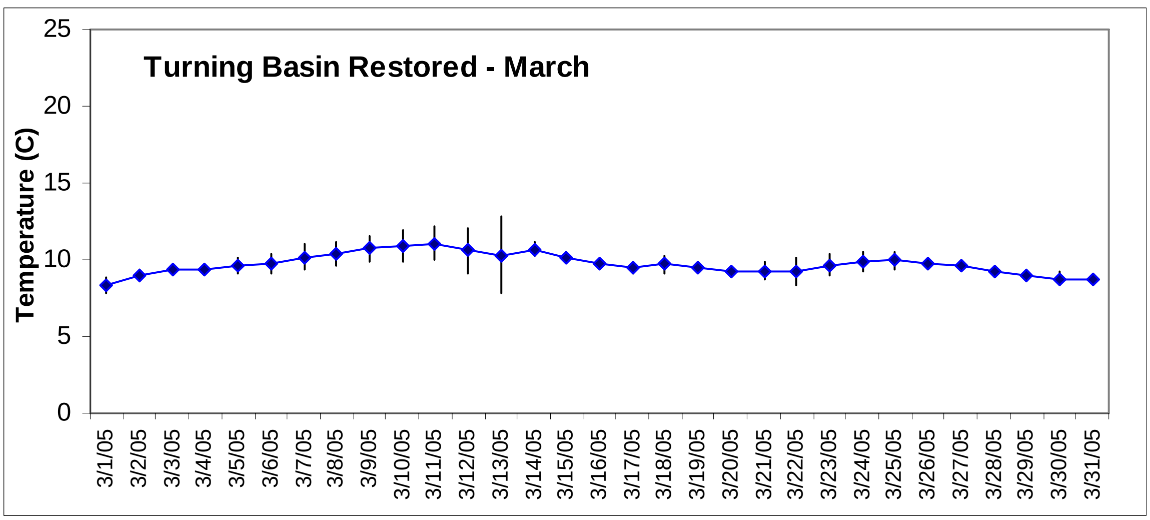
2/26/05
2/27/05
2/28/05


Turning Basin Restored - March
Temperature (C)
25
20
15
10
5
0
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
3/13/05
3/14/05
3/15/05
3/16/05
3/17/05
3/18/05
3/19/05
3/20/05
3/21/05
3/22/05
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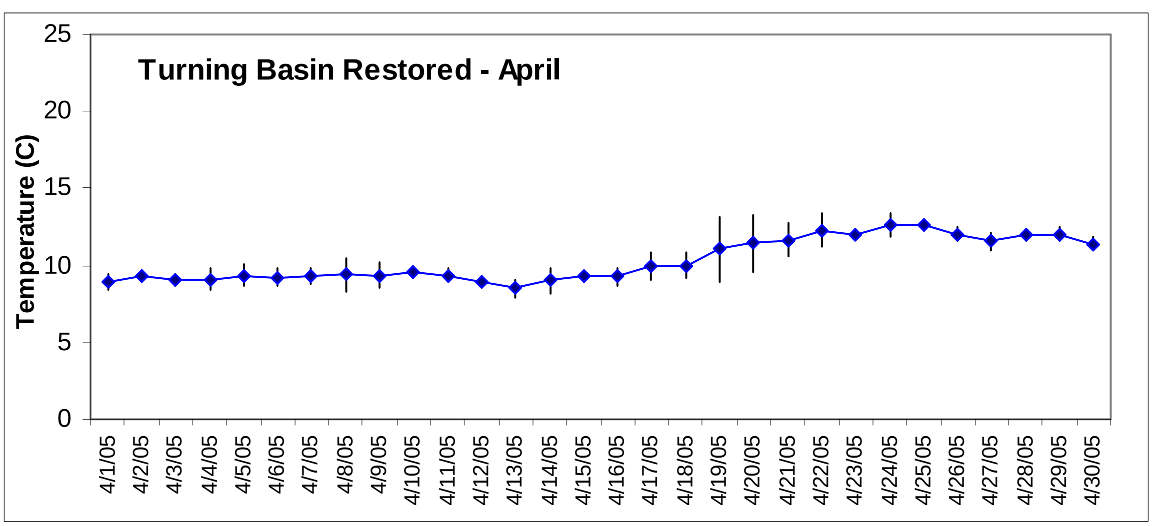
3/30/05
3/31/05


Turning Basin Restored - April
Temperature (C)
25
20
15
10
5
0
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
4/11/05
4/12/05
4/13/05
4/14/05
4/15/05
4/16/05
4/17/05
4/18/05
4/19/05
4/20/05
4/21/05
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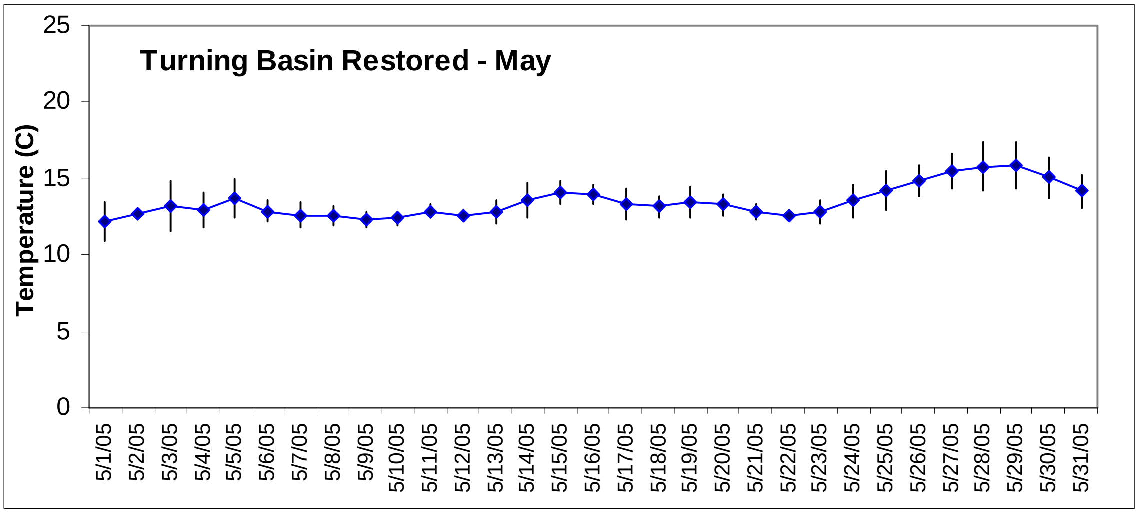
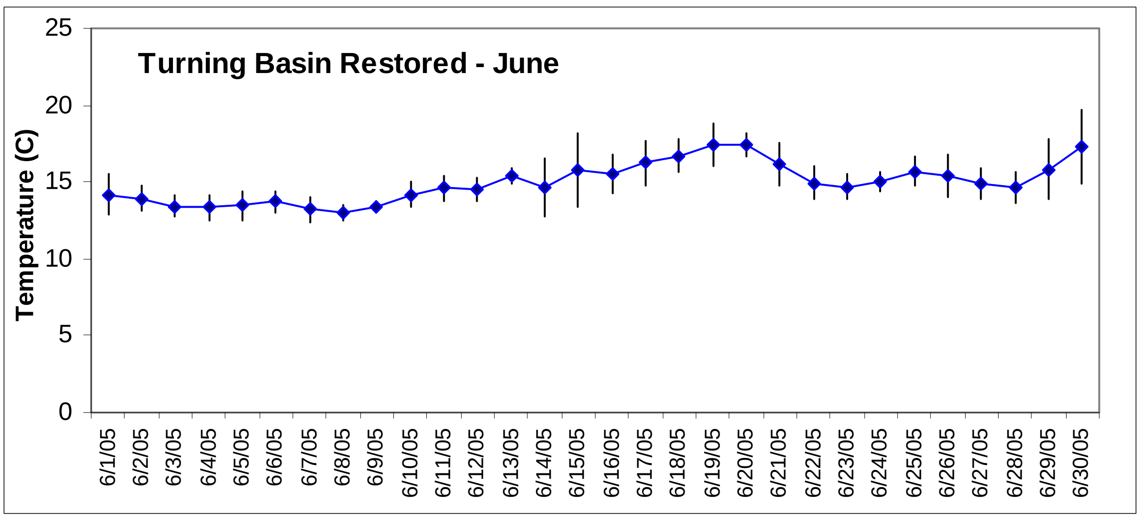
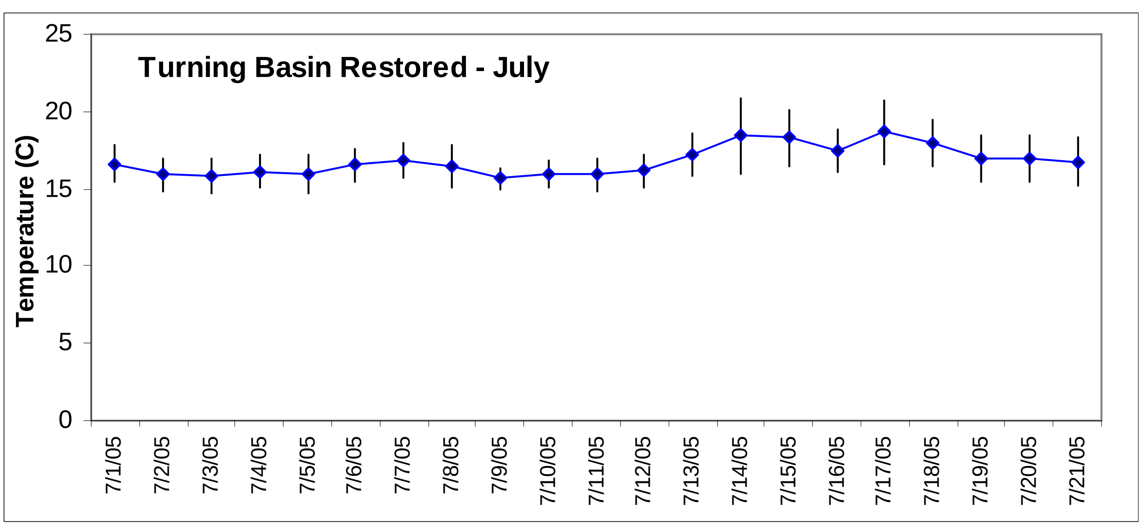
4/28/05
4/29/05
4/30/05


Turning Basin Restored - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
5/20/05
5/21/05
5/22/05
5/23/05
5/24/05
5/25/05
5/26/05
5/27/05
5/28/05
5/29/05
5/30/05
5/31/05


Turning Basin Restored - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
6/18/05
6/19/05
6/20/05
6/21/05
6/22/05
6/23/05
6/24/05
6/25/05
6/26/05
6/27/05
6/28/05
6/29/05
6/30/05


Turning Basin Restored - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
7/13/05
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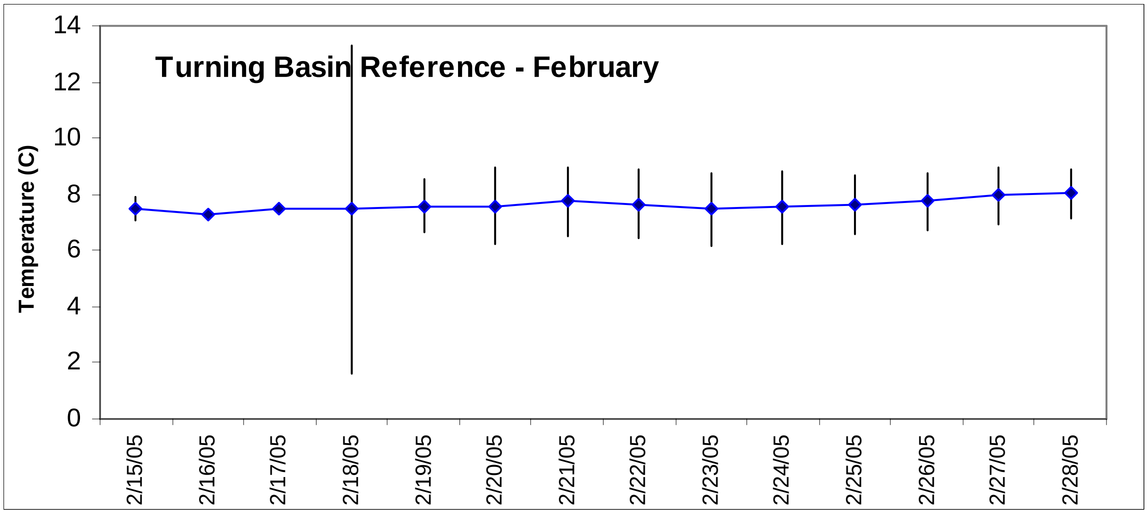
7/19/05
7/20/05
7/21/05


Turning Basin Reference - February
Temperature (C)
0
2
4
6
8
10
12
14
2/15/05
2/16/05
2/17/05
2/18/05
2/19/05
2/20/05
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2/22/05
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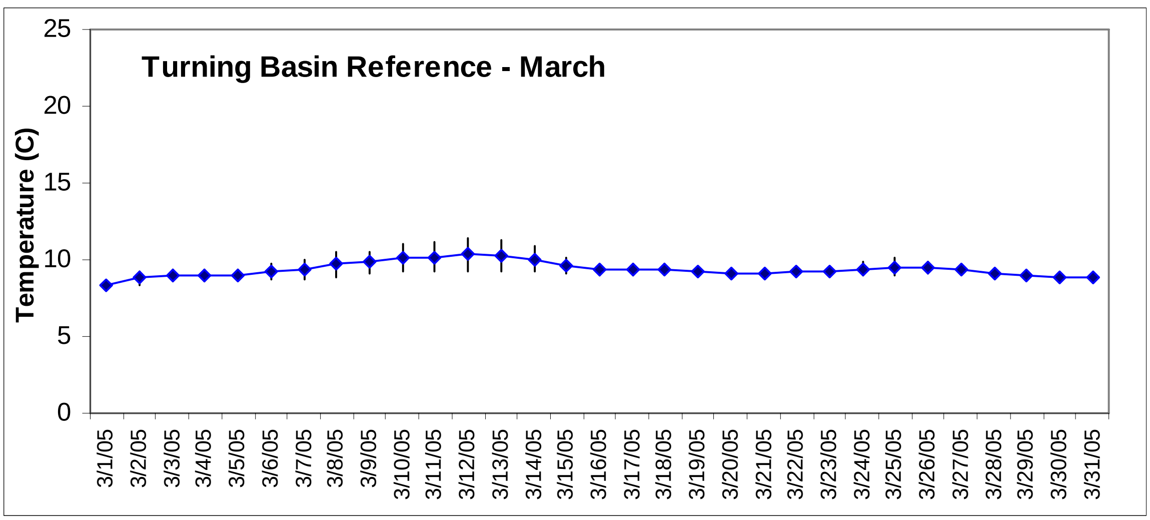
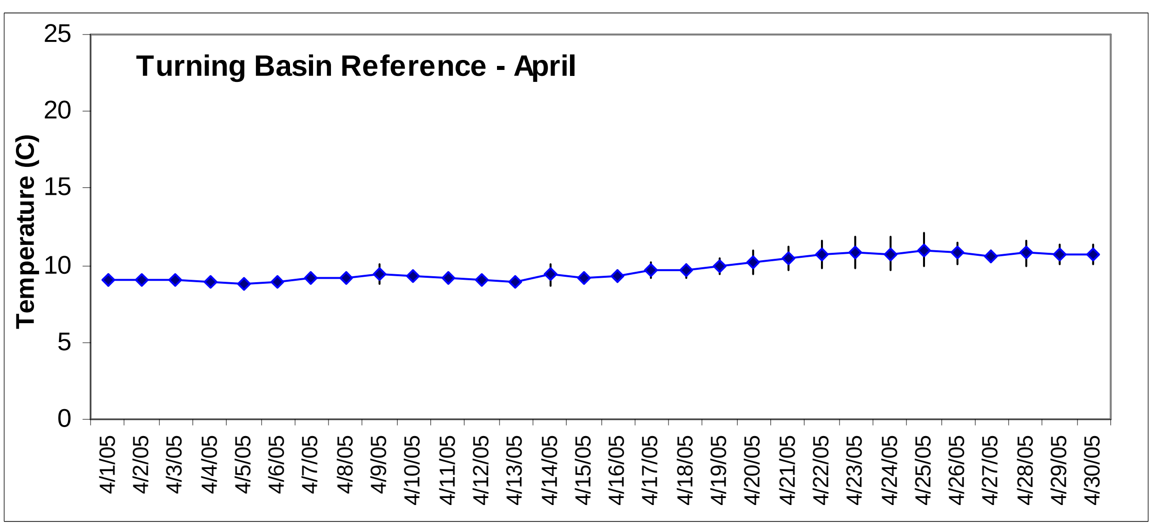
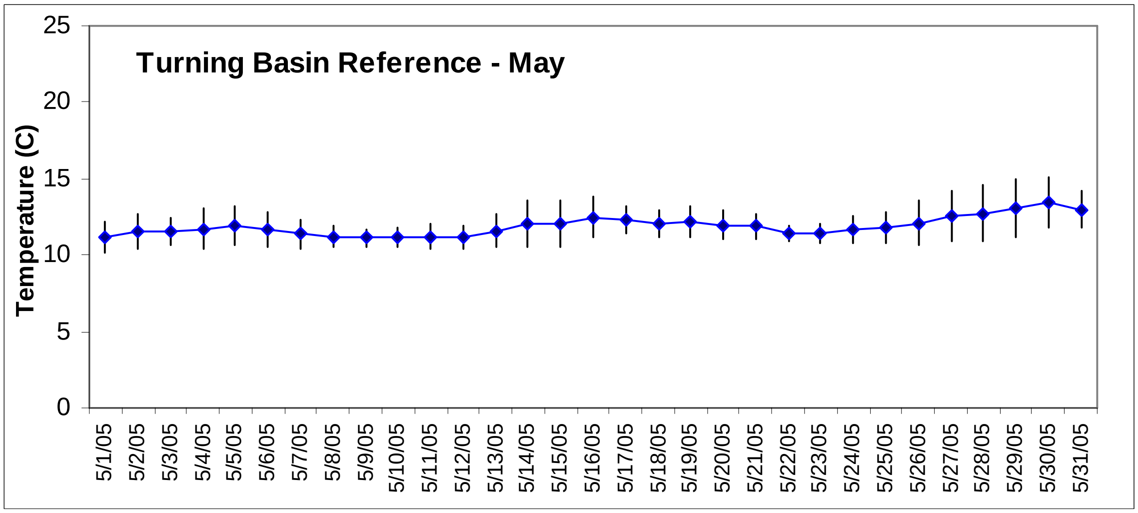
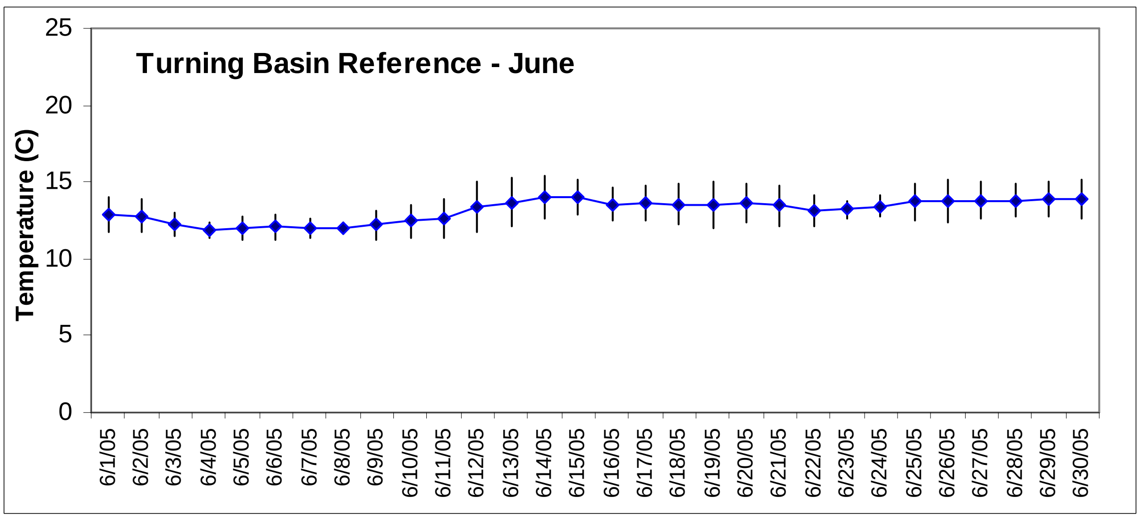
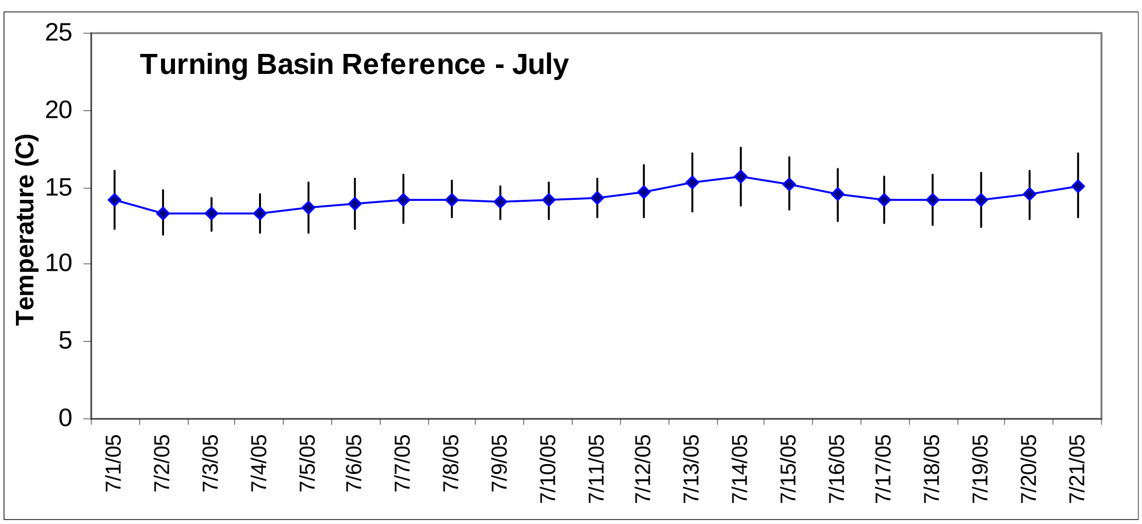
2/27/05
2/28/05


Turning Basin Reference - March
Temperature (C)
0
5
10
15
20
25
3/1/05
3/2/05
3/3/05
3/4/05
3/5/05
3/6/05
3/7/05
3/8/05
3/9/05
3/10/05
3/11/05
3/12/05
3/13/05
3/14/05
3/15/05
3/16/05
3/17/05
3/18/05
3/19/05
3/20/05
3/21/05
3/22/05
3/23/05
3/24/05
3/25/05
3/26/05
3/27/05
3/28/05
3/29/05
3/30/05
3/31/05


Turning Basin Reference - April
Temperature (C)
0
5
10
15
20
25
4/1/05
4/2/05
4/3/05
4/4/05
4/5/05
4/6/05
4/7/05
4/8/05
4/9/05
4/10/05
4/11/05
4/12/05
4/13/05
4/14/05
4/15/05
4/16/05
4/17/05
4/18/05
4/19/05
4/20/05
4/21/05
4/22/05
4/23/05
4/24/05
4/25/05
4/26/05
4/27/05
4/28/05
4/29/05
4/30/05


Turning Basin Reference - May
Temperature (C)
25
20
15
10
5
0
5/1/05
5/2/05
5/3/05
5/4/05
5/5/05
5/6/05
5/7/05
5/8/05
5/9/05
5/10/05
5/11/05
5/12/05
5/13/05
5/14/05
5/15/05
5/16/05
5/17/05
5/18/05
5/19/05
5/20/05
5/21/05
5/22/05
5/23/05
5/24/05
5/25/05
5/26/05
5/27/05
5/28/05
5/29/05
5/30/05
5/31/05


Turning Basin Reference - June
Temperature (C)
25
20
15
10
5
0
6/1/05
6/2/05
6/3/05
6/4/05
6/5/05
6/6/05
6/7/05
6/8/05
6/9/05
6/10/05
6/11/05
6/12/05
6/13/05
6/14/05
6/15/05
6/16/05
6/17/05
6/18/05
6/19/05
6/20/05
6/21/05
6/22/05
6/23/05
6/24/05
6/25/05
6/26/05
6/27/05
6/28/05
6/29/05
6/30/05


Turning Basin Reference - July
Temperature (C)
25
20
15
10
5
0
7/1/05
7/2/05
7/3/05
7/4/05
7/5/05
7/6/05
7/7/05
7/8/05
7/9/05
7/10/05
7/11/05
7/12/05
7/13/05
7/14/05
7/15/05
7/16/05
7/17/05
7/18/05
7/19/05
7/20/05
7/21/05